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ABSTRACT

A SERIES OF MATHEMATICAL MODELS IS GIVEN FOR TRANSLATING A COLLEGE OR UNIVERSITY'S EDUCATIONAL PHILOSOPHY AND ITS OPERATING LEVELS INTO PHYSICAL FACILITY REQUIREMENTS. THE MODELS EXHIBIT THE REQUIRED NUMBER OF UNITS OF INSTRUCTIONAL FACILITIES, BY FUNCTION AND CAPACITY; THE NUMBER OF PROFESSIONAL FACULTY AND GRADUATE TEACHING ASSISTANTS; THE UNITS OF RESEARCH LABORATORIES; THE OFFICE FACILITIES; THE LIBRARY WITH ITS USER AND ACTIVE STORAGE AREAS; THE HOUSING AND DINING FACILITIES; AND THE PARKING FACILITIES. ALL OF THESE ARE EXPRESSED IN UNITS OF THE FACILITIES SO THAT THE MODELS ARE MORE WIDELY APPLICABLE TO VARIOUS TYPES OF EDUCATIONAL INSTITUTIONS. EACH OF THE OPERATIONS CONTAINED WITHIN A SUBMODEL IS FIRST EXPLAINED IN WORDS AND IS THEN EXPRESSED MATHEMATICALLY. (FS)

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AN EXPLORATORY STUDY OF THE PHYSICAL FACILITIES REQUIREMENTS OF INSTITUTIONS OF HIGHER LEARNING

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Introduction

This document is a report of research carried on under the terms of NSF Contract C-454 entitled "An Exploratory Study of the Physical Facilities Requirements of Institutions of Higher Learning", between the National Science Foundation Office of Economic and Manpower Studies and Rensselaer Polytechnic Institute. It represents the culmination of a two and a half year study which had as its purpose the development of a framework for translating an institution's educational philosophy and its operating levels into physical facilities.

The contract called for:

1. Identification and isolation of the variables affecting physical facilities requirements,
2. Formulation of a model (or models) of physical facilities requirements, and
3. Studies of any other facets of the problem that appeared desirable during the progress of the work.

As indicated in the title, this research was conceived, and has been carried out, as an exploratory study.

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Foreword

This exploratory study of the physical facilities of a college or university has resulted in a series of mathematical models of those facilities which are directly necessitated by either the academic activities of the student body or by the presence of a student body.

The mathematical models exhibit the required number of units of instructional facilities, by function and capacity; the number of professional faculty and graduate teaching assistants, both full-time equivalent and actual; the units of research laboratories; the office facilities for faculty, graduate students, research personnel, administration, and secretarial staff; the library with its user and active storage areas; the housing and dining facilities; and the parking facilities. All of these are expressed in units of the facilities so that the models will be more widely applicable to various types of educational institutions. This approach also circumvents the requirement for use of pre-established space standards which may not be appropriate for a particular institution. Instead this approach allows the output units of facilities to be reduced to square feet or space modules through the use of such space factors as an institution deems appropriate to its own educational needs and philosophy.

The models developed show clearly the decisions that must be made in order to determine the requirements for the types of physical facilities considered. The models permit great flexibility in setting the parameters resulting from these decisions and are designed to allow comparison of results of various decisions. The models also allow investigation of the impact of an increase in student enrollment in an academic program or of the introduction of a new academic program on facilities requirements. In fact, these models should be of invaluable assistance in the planning of new facilities, new academic programs, increased student enrollment, or modification of present facilities.

In this report, each of the operations contained within a submodel is first explained in words and is then expressed mathematically.

In order to present the mathematical expression in a single form which can be applied by users having either computer capability or "pencil and paper" capability, matrix notation and techniques have been utilized wherever possible.

Philosophy of the Study

The primary intent of this study has been the initial development of a model which will benefit the planning efforts of the individual institution. Consequently, the main thrust of the project has been concerned with establishing the framework within which institutional operating philosophies can be brought to bear on the input to the system, the student, with the goal being a better understanding of the multitude of interrelationships.

Because of the desire to present a tool which is philosophically oriented toward the individual institution's policies and procedures, the results obtained through application of the various submodels are expressed in terms of "units" of facilities required. Use of space factors has been consistently avoided in an effort to prevent suggesting numerical values which are of questionable applicability to a given situation. The appendix to this report suggests a method by which these "units" of required facilities can be translated into areas based on an institution's own views of its needs.

It should be noted that this philosophy in no way precludes the use of space factors for those institutions which have previously established them.

The Study Procedure

In order to thoroughly investigate the feasibility of constructing a model to project institutional facilities needs, an attempt has been made to construct just such a model. As a result, feasibility can be judged on the basis of the practicality and applicability of the model developed and presented herein. Whenever there are limitations on the types of facilities which can be included in the model or overpowering impracticalities in the treatment of those facilities which were included, feasibility cannot be demonstrated. On the other hand, feasibility can be demonstrated whenever the model, or a portion thereof, shows promise of being capable of implementation.

In judging practicality, or lack thereof, of the various submodels, a note of caution must be introduced. A "model" is nothing more than a mathematical representation of a physical entity-in this case units of facilities. To make this mathematical representation finite and manageable, it is necessary to abstract from reality to a greater or lesser degree. Since the only thing that completely represents reality is reality itself, any attempt to reproduce reality, either mathematically or in some other form, must result in a reproduction which is, to some extent, unfaithful. In this particular case this means that some of those variables which play a role in determining facilities have purposely been omitted. The point of this caveat is that when judging the feasibility of building models of a particular system, the general weaknesses inherent in model-building be considered.

The "system" investigated in this project is, in reality, a group of interconnected sub-systems, each of which is composed of series of operations. The operations are, in turn, composed of the following four basic components:

1. Input - that which is to be acted upon. The system primarily takes the student body and its characteristics as inputs.

2. Decision or Planning Parameters - those which define how the action is to be carried out. The philosophy of the institution regarding such things as size of sections and faculty loads must be expressed in quantitative terms so that they are amenable to mathematical manipulation. Experience indicates that this process of quantification is not as difficult as might be supposed and, further, that the process is an extremely useful vehicle for forcing a review of existing policy. The ability to change this component is the feature which allows this model to be a "simulation model".
3. The Model Itself - that portion which provides the action: it defines how the input and decision parameters are combined so that a final result can be obtained.
4. The Output - the result of the operation. The output may be either an end result of the system - a "final answer" - or it may be intermediate information which later acts as input to another subsystem.

Data Requirements

The eventual ability to actually use some or all of the various submodels which are presented in the subsequent sections of this report depends heavily on the ability to acquire or generate quantitative data concerning the student body, the academic program and course offerings, and the faculty of the institution. Data relating to other elements are also required, but the information on student and faculty and their interactions as expressed through academic programs is generally the most basic.

The required quantified information may serve either as a given input to one or more submodels or as a reflection of an administrative decision.

The following summarizes briefly the kinds of information which must be made available with reference to the three basic areas denoted above.

I. Student Body

The data concerning the student which are required are:

1. Total number of students
2. The number of students in each academic program further categorized by academic level within programs.
3. The student body classified by sex, marital status, and academic level (if the latter is relevant to housing assignments at the institution under consideration).
4. The student body classified by proximity of the students' homes to the campus (as one basis for defining the commuting student).

These data can be aggregated from student records containing the following information on each member of the student body:

1. Academic Program
2. Academic Level
3. Sex
4. Marital Status
5. Home Zip Code

Given these basic data on each member of the student body, it is possible to retrieve the information, concerning either the total student population or selected sub-groups, required by the various submodels.

In addition to the above-mentioned student data, such administrative parameters as 1.) minimum number of library holdings required to support a student of each academic level and program and 2.) percentages of the various sub-groups of the student body to be provided with living, dining, and parking facilities must be established and expressed quantitatively.

II. Course Offerings and Academic Programs

The following information concerning the method of presentation of each course to be offered is required.

1. Any subdivision of the course into lecture, recitation/discussion, and laboratory. (For this purpose, lecture is a course subdivision requiring facilities in which the principal use is for an instructor to address a group of students, while a recitation/discussion subdivision requires facilities which enable complete interplay of discussion between the instructor and the students and a laboratory subdivision requires facilities that are designed for specific use by a student. Laboratories includes such special facilities as gymnasium, music rooms, drawing rooms etc.).
2. For each course subdivision, the maximum number of students to meet at one time.
3. For each course subdivision, the total number of contact hours per week.
4. For each course subdivision, the percentage of FTE instructional load per faculty member (by level of faculty).
5. The source of the students usually enrolled in the course, classified by academic level and program (e.g., 100 per cent of sophomore

engineering students and 100 per cent sophomore science students).

In addition to information on method of course presentation, administrative parameters dealing with factors of support for the academic programs, such as minimum size of library holdings required to initiate a program, must be developed.

III. Faculty

The faculty data required for operation of the submodels developed in this report are included in the "Faculty Profile" of each academic department. The "Faculty Profile" indicates the percentage of the faculty members in each department who fall into pre-established activity categories. The activity categories reflect the most common distributions of faculty effort within the department, a separate category being defined for each such distribution, for example:

100% teaching		
50% teaching	50% Research	
50% teaching		50% Other

The number of categories and the effort breakdowns used must be determined to reflect the practices and needs of each particular institution.

The "Profile" established for illustrative purposes in this report is:

Activity Category	% of Faculty in Category	% Instruction	% Research	% Other	Total % of Effort
1	15	100	0	0	100
2	40	75	25	0	100
3	10	50	50	0	100
4	15	0	100	0	100
5	20	100	0	0	50

The profile can be developed knowing the following information about each faculty member presently assigned to the department under consideration:

1. Academic Department
2. Level
3. % of effort devoted to instructional activities
4. % of effort devoted to research activities
5. % of effort devoted to other activities

In addition to the data required in the development of the Faculty Profile, information on such things as library support required for each faculty member and the ratio of faculty members to secretaries must also be provided.

The above summarized listing is by no means exhaustive; it does, however, provide a reasonable overview as to the types of data required and the amount of detail necessary.

Format of the Model Description

The descriptions of each of the various submodels which have been developed are consistently presented under the following principal headings.

a. Assumptions. The basic assumptions governing the form of the submodels are enumerated.

b. Description of the submodel. A brief description of each of the operations contained within the submodel is provided. The input, decision parameters, and output are described for the individual operations.

c. Symbols. A complete list of the sumbols used in each submodel is provided for ease of reference.

d. Mathematical expression of the sub-system.

e. Diagram. A diagram showing the information flow in schematic form is provided for each submodel.

For ease of reference, the numbering system used has been applied in a manner which allows the description of the model, the mathematical expression of the model, and the diagram to be correlated.

In addition to the descriptions of the specific data required for each of the submodels, a brief description of the more important data files is included. This provides a single location in which the various information elements covering faculty, students, courses and other such items can be noted and collected.

Limitations on the Scope of the Study

For various reasons, certain types of facilities which are common to colleges and universities have been omitted from detailed consideration in this study. Through this omission, it is admitted that the needs for these types of facilities cannot be practically determined through application of systems techniques and models.

Those types of facilities which are more or less outside the realm of model-building are usually characterized by not being closely tied to the instructional processes of the institution. In addition, they generally are those types of which there is only "one-of-a-kind" on each campus (i.e. there will probably be only one such facility on a campus regardless of how much the size and composition of the student body has changed since the facility was initially occupied). Illustrative of such types of space are lounge and recreation areas, museums, student unions, and chapels. They are normally constructed when expedient or when economically possible rather than when the need is generated by a changing student body. Such considerations led to the decision to exclude these kinds of space when developing the model. Because of their complexity and unique requirements, medical schools have also been excluded.

Evening instruction, continuing education programs, and summer programs have not been mentioned specifically. If evening instruction requires less facilities than day instruction, the facilities for day instruction are adequate. If evening instruction requires the greater facilities, then the facilities included in this study are determined by the evening instruction. Continuing education programs, in so far as they require facilities, can be included in the facilities determined in this study. Summer programs, if part of a year-round operation, are to be treated as a regular term; if not part of a year-round operation, the regular facilities of the institution are considered as adequate.

SUBMODEL 1

Instructional Facilities and Faculty

The purpose of Operations 1.1 - 1.17 is to solve the following problem: given a student enrollment by degree program and academic level, to determine for a given term the number and capacity of lecture rooms, recitation/discussion rooms, and instructional laboratories; the F.T.E. faculty and the actual number of faculty, by rank; and the graduate teaching assistants required for instruction in all courses expected to be offered during that term.

To effect the solution of this problem, several decisions - regarding how the academic programs are to be carried out - must be made and expressed quantitatively. The value of these decision parameters may be generated by considering the appropriate records of the institution over a period of years or they may be specified by the institution's plans for the future. Obviously, the values assigned have a great effect on the results obtained; selective variation sheds light on the interacting effects of specific decisions on classroom facilities and faculty required.

This section of the report illustrates the solution of the stated problem by considering the necessary operations for a single course. This illustration is followed by a generalized mathematical model which includes all courses given in a single term. A diagram or chart is also included to show the interrelationships of the several operations in the mathematical model and to illustrate the use of the various parameters.

Assumptions

1. The institution is organized in p instructional degree programs.
2. The students are classified by j levels of study. To illustrate the following seven are used; 1-freshman, 2-sophomores, 3-juniors, 4-seniors, 5-fifth year architects, 6-in professional programs, 7-in graduate programs.
3. Student data are given by numbers of students, by degree program, and level of study.
4. The course enrollments are expressed in the form of a matrix (column vector) $[E]_{nx1}$.
5. The type of instruction in each of these courses can be placed in one or more of the three subdivisions of 1) lecture, 2) recitation/discussion, and 3) laboratory (including drawing and design, gymnasium, music, etc).
6. Instructional unit policies exist concerning the maximum class size in each of the three categories for each course.
7. Faculty engaged in instruction are of b levels. To illustrate the following levels are used: 1) professional faculty members and 2) graduate teaching assistants.
8. Teaching loads for each of the b levels of faculty can be specified for each type t of instruction for each course. (see assumption 5 for types of instruction)
9. Teaching loads may vary by course, by type of course instruction, and by any desired distribution of ranks and levels of faculty among the types of instruction for each course (see assumption 12 for faculty ranks)
10. The teaching load is specified by the fraction of a faculty member's total service to the institution represented by each course section taught.

11. Courses are so labeled that they can be assigned to an instructional department, division, or other unit.

12. Professional faculty ranks r are: 1-professor, 2-associate professor, 3-assistant professor , 4-instructor .

13. The organization of each course as to contact hours per week of instruction in the three subdivisions of lecture, recitation/discussion, and laboratory is specified.

14. Ranges of room capacity have been developed within which the number of hours available for use each week and maximum percentage of room capacity to be occupied for each subdivision of room t, t = 1, 2, 3 are constant (see assumption 13 for room type categories) .

15. All lecture and recitation rooms (subdivision t, t = 1, 2) of the same capacity range have the same available hours for use per week for all courses (subdivision 1 and 2 as listed in assumption 5).

16. Because some laboratories may have more than one student working at the same station on the same experiment, it is advisable to compute the required number of laboratories for each course separately.

17. A set of room capacity ranges, in student stations, has been chosen to include all course subdivisions.

Operation 1.1 - Generate Course Enrollments

Input

The input to Operation 1.1 is the student enrollment by degree program and academic level in a given term.

Decision Parameters

The decision parameters for Operation 1.1 are the percentages of the number of students in each degree program and academic level expected to take each course offered in a given term.

The Operation

Operation 1.1 consists of multiplying 1) the student enrollment categorized according to degree program and academic level by 2) the percentage of the students in each of these categories expected to enroll in each course to be offered in a specified term.

Output

The outputs from Operation 1.1 are the projected course enrollments for a given term.

Operation 1.2 - Form Diagonal Matrix E

Input

The input to this operation is the output from Operation 1,1, the course enrollments.

The Operation

This operation consists of rearranging the course enrollment data into a diagonal matrix format to enable the matrix algebra manipulations of Operation 1.3 to be performed for each course.

Operation 1.3 - Number of Sections by Course Subdivision

Input

The input to Operation 1.3 is the output from Operation 1.2.

Decision Parameters

The decision parameters for Operation 1.3 reflect the practice of organizing courses into various subdivisions (lecture, recitation/discussion, and laboratory). They consist of specifying the number of students considered to be the maximum allowable in each of the subdivisions of each course. In particular, the following information is required for each course:

1. Whether the course instruction is subdivided into
   a. lecture
      and/or
   b. recitation/discussion
      and/or
   c. laboratory (this includes all subdivisions such as drawing - design rooms and gymnasium that require special rooms or equipment).
2. For each subdivision, the maximum number of students allowable per class section.

Note: Each of these items represents a policy decison usually made at the department (division) level.

The Operation

Operation 1.3 consists of dividing each course enrollment (the input) by the maximum number of allowable students per class section for each course subdivision (the decision parameter).

Output

The outputs from Operation 1.3 are the number of sections required for each subdivision of each course.

Operation 1.4 - Convert Output of Operation 1.3 to Integers

The number of sections required for each subdivision of each course, as calculated in Operation 1.3 are likely to be fractional.

Because the unit of instruction is the class section, the number of sections must be an integer. Operation 1.4 consists of converting the outputs of Operation 1.3 into integers. In general, the fractional number of sections should be raised to the next larger integer but, in some cases, it would be advisable to increase slightly the maximum allowable number of students per section to make the number of sections the next lower integer. As an example, for a course with an enrollment of 52 having an associated maximum number of 25 students, it might be advisable to revise the maximum number of students to 26.

Output

The outputs from Operation 1.4 are the integral number of sections required for each subdivision of each course.

Operations 1.5 and 1.6 - F.T.E. Instructional Staff by Level

Operations 1.5 and 1.6 are considered together because they are both concerned with the full time equivalent (F.T.E.) instructional staff and because the operations are mathematically similar.

Input

The inputs to Operations 1.5 and 1.6 are the number of sections required for each subdivision of each course, i. e. the outputs from Operation 1.4.

Decision Parameters

The decision parameters for Operations 1.5 and 1.6 specify the fractional part of an instructional staff member's total duties which is represented by the instruction of one class section in each course subdivision. It is also necessary to specify the level of the instructional staff to be assigned to each section. The simplest specification of levels is to classify the instructional staff as 1) professional faculty and 2) graduate teaching assistants. The categories of instructional staff level used should be only those which are relevant to the assignment of teaching duties at the institution concerned. If courses are assigned only to professional faculty of a given rank, then more levels than two would be needed.

As an illustration for the case where two levels of instructional staff are used, a physics course might have the following decision parameters:

1. Each lecture section represents 1/4 of a faculty member's load.
2. Each recitation section represents 1/4 of a graduate assistant's load, or 1/8 of a faculty member's load.
3. Each laboratory section represents 1/3 of a graduate assistant's load.

It is necessary to modify the loads just given when it is found desirable to factor in a desired distribution of sections between professional faculty and graduate teaching assistants. For example, if it is desired to have one half of the recitation sections taught by faculty and one half by graduate assistants, this can be done by multiplying the loads given above by the fractional distribution desired. Hence, each recitation section requires 1/8 x 1/2 = 1/16 of a faculty member's load and 1/4 x 1/2 = 1/8 of a graduate assistant's load.

The Operation

These operations consist of multiplying the derived number of sections in each subdivision by the instructional load per section, by level. These results may be summed for the two instruction staff levels for each course, if desired.

The following example illustrates this operation. Suppose a physics course requires 4 lecture sections taught by faculty; 36 recitation sections, of which one half are to be taught by faculty and one half by graduate assistants; and 45 laboratory sections taught by graduate assistants. If the teaching loads are as given previously, the following table indicates the calulation of the staff requirements.

Subdivision	No. of Secs.	Load factor/section		Instruction Requirements	
		Faculty	Grad. Asst.	Faculty	Grad. Asst.
Lecture	4	1/4	--	1	--
Recitation	36	1/16	1/8	2.25	4.50
Laboratory	45	--	1/3	--	15.00
		Total F.T.E. Staff by Level		3.25	19.50

Outputs

The outputs from these operations are the F.T.E. instructional staff by course subdivision and staff level or, if summed, by course and staff level.

Operation 1.7 - Staff by Department (Division) and Level

Operation 1.7 consists in merely summing the outputs from Operation 1.5 and 1.6, i.e., the F.T.E. instructional staff by course and subdivision, for each of the two instructional staff levels, for all courses taught in each department (division) and level of faculty required.

Operation 1.8 - Determine Head Count Faculty

Input

The inputs to Operation 1.8 are the outputs of Operation 1.7, i.e., the F.T.E. instructional staff requirements by department (division) and level.

Decision Parameters

The decision parameter for this operation is contained within the data elements of the department profile (the complete structure of the profile is presented in the section entitled Data Elements). In particular, the decision parameter is the ratio of head count faculty to full-time equivalent faculty, by department (division) and by level of faculty. This ratio can be obtained from the profile by multiplying the percent of faculty included in each "activity category" by the "total percent of effort"

Associated with each of the categories, summing the products by department and level of faculty, and relating the resulting percentage to 100.

The Operation

The operation consists of multiplying the F.T.E. instructional staff requirements, categorized by department and level of faculty, by the ratio of head count faculty to F.T.E. faculty which is appropriate for that category.

Output

The output of this operation is head count faculty categorized according to department and level.

Note 1: To better illustrate this particular operation, consider a situation in which the output of Operation 1.7 indicates that 18 F.T.E. senior faculty members were required to staff all courses being offered by the department under consideration.

Activity Category	% of Faculty in Category	% Instruction	% Research	% Other	Total % of Effort
1	15	100	0	0	100
2	40	75	25	0	100
3	10	50	50	0	100
4	15	0	100	0	100
5	20	50	0	0	50

The ratio of total head count to F.T.E. teaching faculty is, therefore, 100: the sum of the products of % of faculty x % instruction x total % of effort or 100: (.15 x 1 x 1 + .40 x .75 x 1 + .10 x .5 x 1 + .15 x 0 x 1 + .20 x .5 x .5) = 100:60

The total head count faculty required is thus 18 x 100/60 = 30.

Note 2: by further exploitation of the data in the profile, a more complete picture of the faculty can be obtained. For example, this data can be used to calculate that

.40 x 30 = 12 faculty members spend 75% of their time in instructional activities (where 40 is the percent of faculty in activity category 1).

.10 x 30 = 3 faculty members divide their time equally between instruction and research (where 10 is the percent of faculty in activity category 3).

Operation 1.9 - Actual Faculty by Rank

Input

The input to Operation 1.9 is one of the outputs from Operation 1.8, i.e., the actual (head count) number of professional faculty, by department (division).

Decision Parameters

The decision parameters for Operation 1.9 are the percentages of the actual professional faculty in each department of rank r the ranks being 1) professor, 2) associate professor, 3) assistant professor, 4) instructor.

The Operation

This operation consists of multiplying the actual number of faculty members in each department by the percentage of faculty of each of the various ranks.

Output

The output from Operation 1.9 gives the actual number of professional faculty, by rank, for each department.

Operation 1.10 - Contact Hours by Course and Subdivision

Input

The input to this operation is the output of Operation 1.4, the integral number of sections required for each subcivision of each course.

Decision Parameters

The decision parameters for Operation 1.10 are the number of class (contact) hours per week required for one section of each of the subdivisions of each course.

The Operation

This operation is performed by multiplying the number of sections of each course subdivision by the number of class (or contact) hours required for each of these sections.

Output

The output from Operation 1.10 is the total number of contact hours required by each subdivision of each course.

Operations 1.11 and 1.12 - Calculate Average Number of Students/Section

Input

The inputs are enrollments by course (from Operation 1.2) and integral number of sections required for each subdivision of each course (from Operation 1.4).

The Operation

Simply stated, these operations consist of dividing the course enrollments by the number of sections required for each subdivision of each course. Due to the use of matrix operations, the mathematical manipulations are slightly more complex. In particular, it is necessary to convert the data on number of sections to reciprocals and then multiply rather than divide.

Output

The output is average enrollment per section of each course subdivision.

Operation 1.13

This operation is merely a rearrangement of the results of Operation 1.12 in order to perform Operation 1.14.

Operation 1.14 - Room Capacity in Student Numbers

Input

The input to this operation is the output of Operation 1.13, the integral number of students per section of each course by subdivision.

Decision Parameters

The decision parameter is the percentage of capacity to which each type and size (or range of sizes) of room should be filled. In other words, this parameter specifies the maximum student station utilization which is acceptable for rooms of various sizes and types (lecture, laboratory, etc.).

The Operation

This operation consists of dividing the average number of students per section of each course subdivision by the maximum student station utilization deemed allowable for rooms having a capacity which is numerically equivalent to the number of students in that section.

Output

The outputs from Operation 1.14 are the minimum required room capacities, expressed in student stations, for each subdivision of each course.

Operation 1.15 - Tally of Weekly Contact Hours by Capacity Ranges

Input

The inputs to this operation are the total number of weekly contact hours for each course, by subdivision (the output from Operation 1.10), and the minimum capacities of the rooms required for each of these course subdivisions (the output from Operation 1.14).

Decision Parameters

The decision parameters for this operation form a mutually exclusive set of room capacity ranges, one of which can be associated with the room requirements of each course subdivision.

The Operation

For lecture and recitation/discussion course subdivisions, the operation consists of summing the weekly contact hour demands within each of the ranges of room capacity. For the laboratory subdivision, the operation consists simply of designating or assigning the room capacity range for each course; weekly contact hour demands remain segregated by course and are not summed within each range of room capacities as they are for the other course subdivisions.

Output

The outputs from this operation are a tally of contact hour demands for lecture rooms and for recitation/discussion rooms by room capacity range and a listing of contact hour demands for laboratories for each course by room capacity range.

Operation 1.16 - Number of Rooms by Capacity and Subdivision Type

Input

The inputs to this operation are the outputs from Operation 1.15.

Decision Parameters

The decision parameters for Operation 1.16 are the maximum number of hours per week during which lecture rooms, recitation/discussion rooms, and laboratories of various capacities are available for use.

The Operation

This operation consists of dividing the weekly contact hour demand for rooms (rooms being categorized by subdivision and capacity range), from Operation 1.15, by the decision parameters, i.e., by the maximum available hours per week for use of such rooms.

Output

The output from Operation 1.16 is the number of required rooms by subdivision type and room capacity.

Note: For lecture rooms and recitation/discussion rooms, the output is the required number of rooms of each size and type. For laboratories, the result is the number of rooms of each size required for each course. The difference in procedure is occasioned by the inability, as a practical matter, of using most laboratories for multiple purpose. Leaving the output in its disaggregated form preserves the ability to collect the requirements of various courses which can share facilities if this is found to be desirable.

Operation 1.17 - Integral Number of Rooms by Capacity and Subdivision

The number of rooms resulting from Operation 1.16 will not be an integer, in general. Operation 1.17 merely consists of increasing the required number of rooms to the next higher integer where the number is fractional.

Note: The following illustrates the operations involved in determining classroom needs by using an example involving a single course.

Consider as input a basic physics course with a total enrollment of 900 (the output of Operation 1.1). In addition, consider that the decision parameters (for Operation 1.3) specify that the course is to be subdivided into:

a. lecture sections no larger than 250 students
b. recitation-discussion groups of no more than 25 students
c. laboratory sections of no more than 20 students.

Operations 1.3 and 1.4 together yield:

a. 900/250 = 3.6 or 4 lecture sections
b. 900/ 25 = 36 recitation sections
c. 900/20 = 45 laboratory sections.

If the decision parameters for Operation 1.10 indicate that

a. lecture sections meet 1 hour per week
b. recitation sections meet 2 hours per week
c. laboratory sections meet 3 hours per week ,

then Operation 1.10 results in a requirement for

a. 4 sections x 1 hour/week = 4 hours per week of lecture rooms
b. 36 sections x 2 hour/week = 72 hours per week of recitation rooms
c. 45 sections x 3 hour/week = 135 hours per week of physics laboratories.

To determine average numbers of students per section, Operation 1.12 requires that the total enrollment in each course be divided by the number of sections as determined in Operation 1.4 so that

a. 900/4 = 225 students per lecture section

b. 900/36 = 25 students per recitation section

c. 900/45 = 20 students per laboratory section.

The parameters for Operation 1.14 require a decision on the maximum percentage station utilization deemed acceptable for rooms of various types and capacities.

Assume these parameters to be as follows:

a. 75% for rooms seating 200 or more

b. 83.3% for rooms seating fewer than 50

c. 100% for all laboratories.

Operation 1.14 is then accomplished by dividing the outputs of Operation 1.12 by the appropriate percentage.

Room requirements are, therefore, for:

a. lecture room of 225/.75 = 300 seat capacity

b. recitation room of 25/.833 = 30 seat capacity

c. laboratories of 20/1.00 = 20 student stations.

Operation 1.15 simply combines the outputs of Operations 1.10 and 1.14 to fully define room requirements as:

a. 4 hour/week of lecture room seating at least 300

b. 72 hour/week of recitation room seating at least 30

c. 135 hour/week laboratory space seating at least 20.

Given that the maximum number of hours of use per week is 24 hours per week for lecture rooms, 27 hours per week for rooms with a capacity of less than 50, and 33 hours per week for physics laboratories, the number of rooms required is

4/24 = 1/6 of a lecture room of 300^+ capacity

72/27 = 2.7 = 3 recitation rooms of 30^+ capacity

135/33 = 4.1 = 5 laboratories with 20 student stations.

Symbols

p = the number of degree programs

j = the student level, $j = 1, 2, \ldots, 7$

n = the number of courses given in a specified term or semester

N_{ij} = the number of students in degree program i, $i = 1, 2, \ldots, p$, at academic level j, $j = 1, 2, \ldots, 7$ in a specified year

$\underset{7p\text{x}1}{[N]}$ = the matrix (column vector) with elements (components) N_{ij}

r_{ijk} = the percentage of N_{ij} who take course k, $k = 1, 2, \ldots, n$, in a given term

$\underset{n\text{x}7p}{[R]}$ = the matrix with elements r_{ijk}

e_k = the student enrollment in course k, $k = 1, 2, \ldots, n$, in a given term

$\underset{n\text{x}1}{[E]}$ = the matrix (column vector) with elements (components) e_k

m_{kt} = the maximum allowable number of students per class section in course k, $k = 1, 2, \ldots, n$, subdivision t, $t = 1, 2, 3$. The three subdivisions are itemized in assumption (5) above.

s_{kt} = the number of sections in course k, subdivision t. The s_{kt} may come out to be fractions.

s'_{kt} = the s_{kt} adjusted to be integers, in general by making them the next larger integer but sometimes by increasing m_{kt} sufficiently to make s'_{kt} the next lower integer

$\underset{3n\text{x}n}{[S]}$ = the matrix with elements s_{kt}

$\underset{3n\text{x}n}{[S']}$ = the matrix with elements s'_{kt}

b = 1, 2 represent the two levels of faculty, professional and graduate assistant respectively

ℓ_{ktb} = the faculty member's teaching load generated by a section of course k and subdivision t, $k = 1, 2, \ldots, n$; $t = 1, 2, 3$; $b = 1, 2$, expressed as a fraction of his total service to the institution, taking into account the desired distribution of instruction between professional faculty and graduate teaching assistants

$\underset{3n\times 3n}{[L_1]}$ = the diagonal matrix with diagonal elements ℓ_{kt1}

$\underset{3n\times 3n}{[L_2]}$ = the diagonal matrix with diagonal elements ℓ_{kt2}

f_{ktb} = the number of F.T.E. faculty of level b to teach each subdivision t of course k, $b = 1, 2$; $t = 1, 2, 3$; $k = 1, 2, \ldots, n$

$\underset{n\times 3n}{[F_1]}$ = the matrix with elements f_{kt1}

$\underset{n\times 3n}{[F_2]}$ = the matrix with elements f_{kt2}

d = the number of instructional departments or divisions

f_{ib} = the total F.T.E. faculty in department or division i and faculty level b, $i = 1, 2, \ldots, d$; $b = 1, 2$

r_{ib} = the ratio of actual faculty to F.T.E. faculty in department or division i and faculty level b, $i = 1, 2, \ldots, d$; $b = 1, 2$

$\underset{d\times d}{[F_{i1}]}$ = the diagonal matrix with diagonal elements f_{i1}

$\underset{d\times d}{[F_{i2}]}$ = the diagonal matrix with diagonal elements f_{i2}

$\underset{d\times d}{[R_{i1}]}$ = the diagonal matrix with diagonal elements r_{i1}

$\underset{d\times d}{[R_{i2}]}$ = the diagonal matrix with diagonal elements r_{i2}

f'_i = the actual member of professional faculty in department or division i, $i = 1, 2, \ldots, d$

f''_i = the actual number of graduate teaching assistants in department or division i, $i = 1, 2, \ldots, d$

$\underset{d\times d}{[F'_i]}$ = the diagonal matrix with diagonal elements f'_i

$\underset{d\times d}{[F_i'']}$ = the diagonal matrix with diagonal elements f_i''

r = 1, 2, 3, 4, the number of ranks of professional faculty

f_{ir} = the actual number of professional faculty of rank r in department or division i, $i = 1, 2, \ldots, d$; $r = 1, 2, 3, 4$

p_{ir} = the percentage of f_i' of rank r

$\underset{d\times 4d}{[F_{ir}]}$ = the matrix with elements f_{ir}

$\underset{d\times 4d}{[P_{ir}]}$ = the matrix with elements p_{ir}

h_{kt} = the total number of contact hours per week for course k, subdivision t

$\underset{n\times 3n}{[H]}$ = the matrix with elements h_{kt}

a_{kt} = the average number of students per section of course k, $k = 1, 2, \ldots, n$, and subdivision t, $t = 1, 2, 3$

$\underset{3n\times n}{[A]}$ = the matrix with elements a_{kt}

a'_{kt} = the average number of students per section (integer) of course k, $k = 1, 2, \ldots, n$, and subidivision t, $t = 1, 2, 3$

$\underset{3n\times n}{[A']}$ = the matrix with elements a'_{kt}

$[A'']$ = the diagonal matrix with diagonal elements a'_{kt} arranged as shown below

y = the number of ranges of room capacities to be used

u_{kt} = the percentage of room capacity for range of room capacity to be occupied by students in course k, $k = 1, 2, \ldots, n$, and subdivision t, $t = 1, 2, 3$

$\underset{3n\times 3n}{[U]}$ = the diagonal matrix with diagonal elements u_{kt} arranged in the same order as elements of $[A'']$

c_{kt} = the number of contact hours per week in course k, subdivision t, $k = 1, 2, \ldots; n$, $t = 1, 2, 3$

$[C]$ = the matrix with elements c_{kt}

C_{kt} = the required room capacity in student stations for course k, k = 1, 2, . . ., n, and room type t, t = 1, 2, 3

$\underset{3n\times 3n}{[C]}$ = the diagonal matrix with diagonal elements C_{kt}

h'_{yt} = the total contact hour demand per week for all courses in subdivision t, t = 1, 2, and in capacity range y, y = 1, 2, . . ., y

h'_{k3y} = the contact hour demand per week for laboratories, t = 3, for course k, k = 1, 2, . . ., n, and capacity range y, y = 1, 2, . . ., y

h''_{yt} = the maximum available hours per week for rooms of subdivision t, t = 1, 2, and range of room capacity y, y = 1, 2, . . ., y

h''_{k3y} = the maximum available hours per week for laboratories for course k, k = 1, 2, . . ., n and range or room capacity y, y = 1, 2, . . ., y

$[H']$ = the diagonal matrix with diagonal elements h'_{yt} and h'_{k3y}, arranged as shown below

$[H'']$= the diagonal matrix with diagonal elements $1/h''_{yt}$ and $1/h''_{k3y}$ arranged as in $[H']$

r_{yt} = the number of rooms of capacity (in student stations) in range y, y = 1, 2, . . ., y for rooms of subdivision t, t = 1, 2

r_{k3y} = the number of laboratories of capacity in range y, y = 1, 2, . . ., y for course k, k = 1, 2, . . ., n

$[R']$ = the diagonal matrix with diagonal elements r_{yt} and r_{k3y}, arranged as in $[H']$

r'_{yt} = the integral number of rooms of capacity (in student stations) in range y, y = 1, 2, . . ., y for rooms of subdivision t, t = 1, 2

r'_{k3y} = the integral number of laboratories of capacity in range y, y = 1, 2, . . ., y for course k, k = 1, 2, . . ., n

$[R_1']$ = the diagonal matrix with diagonal elements r'_{yt} and r'_{k3y}

The Models

Operation 1.1 - Generate Course Enrollments

$$\underset{7px1}{[N]} = [N_{11}\ N_{12}\ .\ .\ .N_{17}\ N_{21}\ N_{22}\ .\ .\ .N_{27}\ .\ .\ .N_{p1}\ N_{p2}\ .\ .\ .N_{p7}]^T$$

where T indicates the transpose of the matrix (row vector).

$$\underset{nx7p}{[R]} = \underset{nx7p}{\begin{bmatrix} r_{111} & r_{121} & .\ .\ .r_{171} & r_{211} & r_{221} & .\ .\ .r_{271} & .\ .\ .r_{p11} & .\ .\ .r_{p71} \\ r_{112} & r_{122} & .\ .\ .r_{172} & r_{212} & r_{222} & .\ .\ .r_{272} & .\ .\ .r_{p12} & .\ .\ .r_{p72} \\ . & . & . & . & . & . & . & . \\ r_{11n} & r_{12n} & .\ .\ .r_{17n} & r_{21n} & r_{22n} & .\ .\ .r_{27n} & .\ .\ .r_{p1n} & .\ .\ .r_{p7n} \end{bmatrix}}$$

Then

$$\underset{nx1}{[E]} = [e_1\ e_2\ .\ .\ .e_n] = \underset{nx7p}{[R]} \times \underset{7px1}{[N]}$$

Operation 1.2 - Form Diagonal Matrix E

$$\underset{nxn}{[E_1]} = \text{diag}\ \underset{nxn}{[e_1\ e_2\ .\ .\ .e_n]}$$

Operation 1.3 - Number of Sections by Course Subdivision

$$\text{Let } \underset{3nxn}{[M]} = \begin{bmatrix} 1/m_{11} & 0 & 0\ .\ .\ .\ 0 & 0 \\ 1/m_{12} & 0 & 0\ .\ .\ .\ 0 & 0 \\ 1/m_{13} & 0 & 0\ .\ .\ .\ 0 & 0 \\ 0 & 1/m_{21} & 0\ .\ .\ .\ 0 & 0 \\ 0 & 1/m_{22} & 0\ .\ .\ .\ 0 & 0 \\ 0 & 1/m_{23} & 0\ .\ .\ .\ 0 & 0 \\ . & . & . & . \\ 0 & . & .\ .\ .\ 0 & 1/m_{n1} \\ 0 & . & .\ .\ .\ 0 & 1/m_{n2} \\ 0 & . & .\ .\ .\ 0 & 1/m_{n3} \end{bmatrix}$$

Note: If course k has one or more of the three subdivisions missing, the corresponding $1/m_{kt}$ is replaced by 0.

Then

$$\underset{3n\times n}{[S]} = \begin{bmatrix} s_{11} & 0 & \cdots & 0 & 0 \\ s_{12} & 0 & \cdots & 0 & 0 \\ s_{13} & 0 & \cdots & 0 & 0 \\ 0 & s_{21} & \cdots & 0 & 0 \\ 0 & s_{22} & \cdots & 0 & 0 \\ 0 & s_{23} & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & 0 & s_{n1} \\ 0 & 0 & \cdots & 0 & s_{n2} \\ 0 & 0 & \cdots & 0 & s_{n3} \end{bmatrix} = \underset{3n\times n}{[M]} \times \underset{n\times n}{[E_1]}$$

Operation 1.4 - Convert Output of Operation 1.3 to Integers

$$\underset{3n\times n}{[S']} = \begin{bmatrix} s'_{11} & 0 & \cdots & 0 & 0 \\ s'_{12} & 0 & \cdots & 0 & 0 \\ s'_{13} & 0 & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & \cdots & \cdots & 0 & s'_{n1} \\ 0 & \cdots & \cdots & 0 & s'_{n2} \\ 0 & \cdots & \cdots & 0 & s'_{n3} \end{bmatrix}$$

Operation 1.5 - Determine F.T.E. Number of Senior Professional Staff

$$\underset{3n\times 3n}{[L_1]} = \text{diag} \underset{3n\times 3n}{[\ell_{111}\ \ell_{121}\ \ell_{131}\ \ell_{211}\ \cdots\ \ell_{n31}]}$$

$$\underset{nx3n}{[F_1]} = \begin{bmatrix} f_{111} & f_{121} & f_{131} & 0 & 0 & 0 & 0 & \cdots\cdots & 0 & 0 & 0 \\ 0 & 0 & 0 & f_{211} & f_{211} & f_{231} & 0 & \cdots\cdots & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots\cdots & 0 & 0 & 0 \\ 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots\cdots & f_{n11} & f_{n21} & f_{n31} \end{bmatrix} = \underset{nx3n}{[S']^T} \times \underset{3nx3n}{[L_1]}$$

Operation 1.6 - Determine F.T.E. Graduate Teaching Assistants

$$\underset{3nx3n}{[L_2]} = \text{diag } [\ell_{112}\ \ell_{122}\ \ell_{132}\ \ell_{212}\ \ldots\ell_{n32}]$$

$$\underset{nx3n}{[F_2]} = \underset{nx3n}{\begin{bmatrix} f_{112} & f_{122} & f_{132} & 0 & \cdots\cdots & 0 & 0 & 0 \\ 0 & 0 & 0 & f_{212} & f_{222} & f_{232} \cdots & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & \cdots & \cdots & \cdots & \cdots & \cdots & f_{n12} & f_{n22} & f_{n32} \end{bmatrix}} = \underset{nx3n}{[S']^T} \times \underset{3nx3n}{[L_2]}$$

Operation 1.7 - F.T.E. Staff By Department and Level

Sum the F.T.E. instructional staff for each level 1 and 2, for all courses taught in each department (division) i, i = 1, 2, . . ., d, thus obtaining f_{ib}, b = 1, 2

Operation 1.8 - Determine Head Count Faculty

$$\underset{dxd}{\text{diag } [F_i']} = \underset{dxd}{\text{diag } [F_1'\ \ F_2' \ldots F_d']} = \underset{dxd}{\text{diag } [F_{i1}]} \times \underset{dxd}{\text{diag } [R_{i1}]}$$

$$\underset{dxd}{\text{diag } [F_i'']} = \underset{dxd}{\text{diag } [f_1''\ \ f_2'' \ldots f_d'']} = \underset{dxd}{\text{diag } [F_{i2}]} \times \underset{dxd}{\text{diag } [R_{i2}]}$$

Operation 1.9 - Actual Faculty by Rank

$$\underset{dx4d}{[F_{ir}]} = \begin{bmatrix} f_{11} & f_{12} & f_{13} & f_{14} & 0 & 0 & 0 & 0 & \cdots\cdots & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & f_{21} & f_{22} & f_{23} & f_{24} & \cdots\cdots & 0 & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots\cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots\cdots & f_{d1} & f_{d2} & f_{d3} & f_{d4} \end{bmatrix}$$

$$= \text{diag } \underset{dxd}{[F_i']} \times \underset{dx4d}{[P_{ir}]}$$

Operation 1.10 - Contact Hours by Course and Subdivision

$$\underset{nx3n}{[C]} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & 0 & 0 & c_{21} & c_{22} & c_{23} & \cdots & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & c_{n1} & c_{n2} & c_{n3} \end{bmatrix}$$

and $$\underset{3nx3n}{[S'_2]} = \begin{bmatrix} s'_{11} & & & & & & & \\ & s'_{12} & & & & & \bigcirc & \\ & & s'_{13} & & & & & \\ & & & s'_{21} & & & & \\ & & & & s'_{21} & & & \\ & \bigcirc & & & & s'_{23} & & \\ & & & & & & \ddots & \\ & & & & & & & S'_{n3} \end{bmatrix}$$

Then

$$\underset{nx3n}{[H]} = \begin{bmatrix} h_{11} & h_{12} & h_{13} & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & 0 & 0 & h_{21} & h_{22} & h_{23} & \cdots & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & h_{n1} & h_{n2} & h_{n3} \end{bmatrix} = \underset{nx3n}{[C]} \times \underset{3nx3n}{[S'_2]}$$

Operation 1.11 and 1.12 - Calculate Average Number of Students/Section

Let
$$\underset{3nxn}{[S'_1]} = \begin{bmatrix} 1/s'_{11} & 0 & 0 & \cdots & 0 \\ 1/s'_{12} & 0 & 0 & \cdots & 0 \\ 1/s'_{13} & 0 & 0 & \cdots & 0 \\ 0 & 1/s'_{21} & 0 & \cdots & 0 \\ 0 & 1/s'_{22} & 0 & \cdots & 0 \\ 0 & 1/s'_{23} & 0 & \cdots & 0 \\ 0 & 0 & 0 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & \cdots & 0 & \cdots\, 0 & 1/s'_{n1} \\ 0 & \cdots & 0 & \cdots\, 0 & 1/s'_{n2} \\ 0 & \cdots & 0 & \cdots\, 0 & 1/s'_{n3} \end{bmatrix}$$

Then
$$\underset{3nxn}{[A]} = \begin{bmatrix} a_{11} & 0 & \cdots & 0 & 0 \\ a_{12} & 0 & \cdots & 0 & 0 \\ a_{13} & 0 & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & 0 & a_{n1} \\ 0 & 0 & \cdots & 0 & a_{n2} \\ 0 & 0 & \cdots & 0 & a_{n3} \end{bmatrix} = \underset{3nxn}{[S'_1]} \times \underset{nxn}{[E_1]}$$

Note: If any of the s'_{kt} are zero, the corresponding $1/s'_{kt}$ is replaced by 0.

and

$$\underset{3nxn}{[A']} = \begin{bmatrix} a'_{11} & \cdots & 0 & 0 \\ a'_{12} & \cdots & 0 & 0 \\ a'_{13} & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & \cdots & 0 & a'_{n1} \\ 0 & \cdots & 0 & a'_{n2} \\ 0 & \cdots & 0 & a'_{n3} \end{bmatrix}$$

Operation 1.13 -

$$\underset{3n\times 3n}{\text{Diag }[A'']} = \underset{3n\times 3n}{\text{diag }[a'_{12}\ a'_{12}\ a'_{21}\ a'_{22}}\ \ldots\ldots\ a'_{n2}\ a'_{13}\ a'_{23}\ \ldots\ldots\ a'_{n3}]$$

Operation 1.14 - Room Capacity in Student Numbers

$$\underset{3n\times 3n}{\text{Diag }[U]} = \text{diag }[1/u_{11}\ 1/u_{12}\ 1/u_{21}\ 1/u_{22}\ \ldots\ 1/u_{n2}\ 1/u_{13}\ 1/u_{23}\ \ldots\ldots\ 1/u_{n3}]$$

$$\underset{3n\times 3n}{\text{diag }[C]} = \text{diag }[C_{11}\ C_{12}\ C_{21}\ C_{22}\ \ldots\ C_{n2}\ C_{13}\ \ldots\ C_{n3}] = \underset{3n\times 3n}{\text{diag }[A'']} \times \underset{3n\times 3n}{\text{diag }[U]}$$

Operation 1.15 - Tally of Weekly Contact Hours by Capacity Ranges

Sum up contact hour demand for all courses of subdivision t, t = 1, 2, from [H] in capacity range y from [C]. For laboratories t = 3, obtain h'_{k3y} similarly. These together form [H'].

$$\underset{(n+2)y\times(n+2)y}{\text{diag }[H']} = \underset{(n+2)y\times(n+2)y}{\text{diag }[h'_{11}\ h'_{12}\ h'_{21}\ h'_{22}}\ \ldots\ h'_{y2}\ h'_{131}\ h'_{132}\ \ldots\ h'_{13y}\ h'_{231}\ \ldots\ h'_{23y}\ \ldots\ h'_{n3y}]$$

Operation 1.16 - Number of Rooms by Capacity and Subdivision Type

$$\underset{(n+2)y\times(n+2)y}{\text{diag }[H'']} = \underset{(n+2)y\times(n+2)y}{\text{diag }[1/h''_{11}\ 1/h''_{12}\ 1/h''_{21}}\ \ldots\ 1/h''_{y2}\ 1/h''_{131}\ \ldots\ 1/h''_{n3y}]$$

$$\underset{(n+2)y\times(n+2)y}{\text{diag }[R']} = \underset{(n+2)y\times(n+2)y}{\text{diag }[r_{11}\ r_{12}\ r_{21}}\ \ldots\ r_{y2}\ r_{131}\ \ldots\ r_{n3y}] = \underset{(n+2)y\times(n+2)y}{\text{diag }[H']} \times \underset{(n+2)y\times(n+2)y}{\text{diag }[H'']}$$

Operation 1.17 - Integral Number of Rooms by Capacity and Subdivision Type

$$\underset{(n+2)y\times(n+2)y}{\text{diag }[R'_1]} = \text{diag }[r'_{11}\ r'_{12}\ r'_{21}\ \ldots\ r'_{y2}\ r'_{131}\ \ldots\ r'_{n3y}]$$

where r'_{yt} and r'_{k3y} are the next higher integers than r_{yt} and r_{k3y}, respectively.

Remark: Instead of computing the number of rooms by capacity and subdivision, using the matrix [R'], the number of rooms for instruction of subdivision t, t = 1, 2, can be computed as one operation and the number of laboratories t = 3, can be computed separately as a second unit.

SUBMODEL 2

Research Facilities

Research, as performed in educational institutions, can be classified as either theoretical research or experimental research, theoretical research being that performed in the library and/or offices; experimental research being that which requires laboratory facilities.

The problems to be solved by the operations in Submodel #2 are as follows: 1) given the actual number of professional faculty by department (division), to find the number of faculty members to be provided with experimental research laboratories; 2) given the student enrollment by degree program and academic level, to find the number of students within each of these degree programs to be provided with experimental research laboratories.

The answers to these relatively straightforward questions can be generated by performing the operations contained within Submodel 2. It is realized that a significant portion of the research space requirements of many departments results from demands made by specialized equipment (linear accelerators, etc.). Because of the highly individualized nature of these requirements, no attempt is made to include them in the models.

This section of the report describes, in words, the operations which convert the inputs into the required outputs specifying research facilities requirements. This description is followed by the associated mathematical models. A diagram showing the operations in the mathematical models and the parameters used is included also.

Assumptions

1. All research activities are classified as either theoretical research or experimental research.
2. Facilities for all theoretical research are provided by offices and library facilities.
3. Experimental research may be pursued by faculty, research staff, graduate students, and undergraduate students.
4. Large experimental research facilities, e.g., nuclear reactors, are considered separately from other experimental research facilities.
5. All experimental research laboratories are to be available for use 100% of the time.

Operation 2.1 - Faculty Experimental Research Laboratories

Input

The input to Operation 2.1 is the output from Operation 1.8, the actual number of professional faculty in each department (division).

Decision Parameters

The decision parameters for this operation are the percentages of professional faculty in each department (division) who are engaged in experimental research.

The Operation

Operation 2.1 consists of multiplying the number of professional faculty in each department (division) by the percentage of this faculty engaged in experimental research.

Output

The outputs from Operation 2.1 are the number of actual professional faculty in each department (division) engaged in experimental research and, assuming each such faculty member requires an individual laboratory, this is the number of laboratories required for professional faculty experimental research.

Operation 2.2 - Student Enrollment by Degree Program

Input

The input to this operation is the standard input to Operation 1.1, i.e., the student enrollment by degree program and academic level.

The Operation

This operation is the summation of the student enrollment in each degree program for all academic levels.

Output

The outputs from Operation 2.2 are the total student enrollments in each degree program.

Operation 2.3 - Number of Students, by Degree Program, Engaged in Experimental Research

Input

The input to Operation 2.3 is the output from Operation 2.2, i.e., the total student enrollment in each degree program.

Decision Parameters

The decision parameters are the percentages of the total student enrollment in each degree program who engage in experimental research.

The Operation

Operation 2.3 consists of multiplying the total student enrollment in each degree program by the percentage of this total student enrollment who engage in experimental research.

Output

The outputs from Operation 2.3 are the number of students in each degree program who engage in experimental research.

Operation 2.4 - Formation of Row Vector for Use in Operation 2.5

Operation 2.4 consists merely of separating the number of students in each degree program, who engage in experimental research, for use in the next operation.

Operation 2.5 - Number of Students, by Degree Program, Engaged in Each Experimental Research Project

Input

The inputs to this operation are the outputs from Operation 2.4, i. e., the number of students in each degree program, who engage in experimental research.

Decision Parameters

The decision parameters for Operation 2.5 are the percentages of students in each degree program who are engaged in each different research project having students from that degree program.

The Operation

Operation 2.5 consists of multiplying the number of students in each degree program, who engage in experimental research, by percentage of students in that degree program who are engaged in each different research project having students from that degree program.

Output

The outputs from Operation 2.5 are the number of students in each degree program who are engaged in each different research project having students from that degree program.

Operation 2.6 - Number of Student Experimental Research Laboratories

Input

The inputs to Operation 2.6 are the outputs from Operation 2.5, i.e., the number of students in each degree program who are engaged in each different research project having students from that degree program.

Decision Parameters

The decision parameters for this operation are the maximum number of allowable students per experimental laboratory for each different research project having students from each degree program.

The Operation

This operation consists of dividing the number of students in each degree program who are engaged in each research project, having students from that degree program, by the maximum number of allowable students per experimental laboratory for each different research project having students from that degree program.

Output

The outputs from Operation 2.6 are the number of experimental laboratories required for students engaged in each research project by degree program.

Operation 2.7 - Capacity of Student Research Laboratories

Input

The inputs to Operation 2.7 are the maximum number of allowable students per experimental laboratory for each different research project, arranged by degree program.

Decision Parameters

The decision parameters for this operation are the number of students to be assigned to a laboratory station for each different research project within a degree program.

The Operation

This operation consists of dividing the maximum number of allowable students per experimental laboratory for each different research project in a degree program by the number of students per laboratory station for each different research project in that degree program.

Output

The outputs from Operation 2.7 are the laboratory capacities, in stations, for each different research project in a degree program.

Operations 2.8 and 2.9 - Laboratory Facilities for Research Staff and Large Experimental Installations

These operations merely insure that the experimental laboratories needed by the research staff and those necessitated by the presence of special (large) experimental installations (e.g. nuclear reactors) are included in the experimental laboratory requirements.

Symbols

f'_i = the actual number of professional faculty in department (division) i, $i = 1, 2, \ldots, d$, as before

$\underset{d \times d}{[F'_i]}$ = the diagonal matrix with diagonal elements f'_i

d = the number of departments or divisions

r'_{ix} = the percentage of actual professional faculty in department (division) i, $i = 1, 2, \ldots, d$, engaged in experimental research

$\underset{d \times d}{[R'_{ix}]}$ = the diagonal matrix with diagonal elements r'_{ix}

N'_{ix} = the number of actual professional faculty in department (division) i, $i = 1, 2, \ldots, d$, engaged in experimental research = the number of experimental research laboratories required by the professional faculty in department (division) i

$\underset{d \times d}{[N'_{ix}]}$ = the diagonal matrix with diagonal elements N'_{ix}

X = the number of areas of experimental research, current and/or planned, for the research staff in a given year

N_{ij} = the student enrollment by degree program i, $i = 1, 2, \ldots, p$, and academic level j, $j = 1, 2, \ldots, 7$, as used previously

$[N_i]$ = the row vector giving the student enrollment in degree program i, $i = 1, 2, \ldots, p$

p''_i = the percentage of N_i who engage in experimental research

$\underset{p \times p}{[P''_i]}$ = the diagonal matrix with diagonal elements p''_i

N_{ix} = the number of students in degree program i, $i = 1, 2, \ldots, p$, who engage in experimental research

$\underset{1 \times p}{[N_{ix}]}$ = the row vector with components N_{ix}

$n(i)$ = the number of research projects with students from degree program i, $i = 1, 2, \ldots, p$

r_{iK} = the percentage of students in degree program i, $i = 1, 2, \ldots, p$, who are engaged in research project K, $K = 1, 2, \ldots, n(i)$, having students from degree program i, $i = 1, 2, \ldots, p$

$[N_{iK}]$ = the row vector with components which are the number of students in degree programs, $i = 1, 2, \ldots, p$, who are engaged in research project K, $K = 1, 2, \ldots, n(i)$, having students from degree program i

m_{iK} = the maximum number of allowable students per experimental laboratory for project K, $K = 1, 2, \ldots, n(i)$, having students from degree program i, $i = 1, 2, \ldots, p$

$[M_{iK}]_{1 \times n(i)}$ = the row vector with components m_{iK}

$[L'_i]_{1 \times n(i)}$ = the row vector with components which are the number of experimental laboratories required for students engaged in research project K, $K = 1, 2, \ldots, n(i)$, having students from degree programs i, $i = 1, 2, \ldots, p$

u_{iK} = the number of students per laboratory station in research project K, $K = 1, 2, \ldots, n(i)$, having students from degree program i, $i = 1, 2, \ldots, p$

$[C'_{iK}]_{1 \times n(i)}$ = the row vector with components which are the laboratory capacity for research project K, $K = 1, 2, \ldots, n(i)$, having students from degree program i, $i = 1, 2, \ldots, p$

X = total number of research staff experimental laboratories

X_1 = the total number of large experimental installations, e.g. nuclear reactors

$[R_{iK}]$ = row vector with elements r_{iK}

The Models

Operation 2.1 - Faculty Experimental Research Laboratories

$$\underset{dxd}{\text{diag }[N'_{ix}]} = \underset{dxd}{\text{diag }[F'_{i}]} \text{ x } \underset{dxd}{\text{diag }[R'_{ix}]} = \underset{dxd}{\text{diag }[N'_{1x}\ N'_{2x}\ .\ .\ .\ N'_{dx}]}$$

Note: If the department (division) profiles are sufficiently detailed, this computation need not be made as the quantities N'_{ix} can be determined from these profiles.

Operation 2.2 - Student Enrollment by Degree Program

$$\underset{1xp}{[N_i]} = \sum_{j=1}^{7} N_{ij},\ i = 1, 2, .\ .\ .\ , p,\ \underset{1xp}{[N_i]} = [N_1\ N_2\ .\ .\ .\ N_p]$$

Operations 2.3 and 2.4 - Number of Students by Degree Program Engaged in Experimental Research

$$\underset{1xp}{[N_{ix}]} = \underset{1xp}{[N_i]} \text{ x } \underset{pxp}{\text{diag }[P''_i]} = \underset{1xp}{[N_1\ N_2\ .\ .\ .\ N_p]} \text{ x } \underset{pxp}{\text{diag }[P''_1\ P''_2\ .\ .\ .\ P''_p]}$$

$$= \underset{1xp}{[N_{1x}\ N_{2x}\ .\ .\ .\ N_{px}]}$$

Operation 2.5 - Number of Students, by Degree Program, Engaged in Each Experimental Research Project

$$\underset{1xn(1)}{[N_{1K}]} = N_{1x}\ \underset{1xn(1)}{[r_{11}\ r_{12}\ .\ .\ .\ r_{1n(1)}]}$$

$$\underset{1xn(2)}{[N_{2K}]} = N_{2x}\ \underset{1xn(2)}{[r_{21}\ r_{22}\ .\ .\ .\ r_{2n(2)}]}$$

. . . .

$$\underset{1xn(p)}{[N_{pK}]} = N_{px}\ \underset{1xn(p)}{[r_{p1}\ r_{p2}\ .\ .\ .\ r_{pn(p)}]}$$

Operation 2.6 - Number of Student Experimental Research Laboratories

$$\underset{1xn(1)}{[L'_1]} = \underset{1xn(1)}{[N_{1K}]} \text{ x } \underset{n(1)xn(1)}{\text{diag }[1/m_{11}\ 1/m_{12}\ .\ .\ .\ 1/m_{1n(1)}]}$$

$$\underset{1xn(2)}{[L'_2]} = \underset{1xn(2)}{[N_{2K}]} \text{ x } \underset{n(2)xn(2)}{\text{diag }[1/m_{21}\ 1/m_{22}\ .\ .\ .\ 1/m_{2n(2)}]}$$

. . . .

$$\underset{1\times n(p)}{[L'_p]} = \underset{1\times n(p)}{[N_{pK}]} \times \underset{n(p)\times n(p)}{\text{diag}\,[1/m_{p1}\ \ 1/m_{p2}\ \ \ldots\ \ 1/m_{pn(p)}]}$$

Operation 2.7 - Capacity of Student Research Laboratories

$$\underset{1\times n(1)}{[C'_{1K}]} = \underset{1\times n(1)}{[M_{1K}]} \times \underset{n(1)\times n(1)}{\text{diag}\,[1/u_{11}\ \ 1/u_{12}\ \ \ldots\ \ 1/u_{1n(1)}]}$$

. . . .

$$\underset{1\times n(p)}{[C'_{pK}]} = \underset{1\times n(p)}{[M_{pK}]} \times \underset{n(p)\times n(p)}{\text{diag}\,[1/u_{p1}\ \ 1/u_{p2}\ \ \ldots\ \ 1/u_{pn(p)}]}$$

Note: The row vectors $[N'_{iK}]$, $[L_i]$, and $[C'_{iK}]$ are computed separately because $n(i)$ is likely to be different for each degree program i, $i = 1, 2, \ldots, p$. Moreover, some programs will have no experimental laboratory requirements and so these computations need not be done for such programs.

Operation 2.8 - Research Staff Experimental Laboratories

$$X$$

Operation 2.9 - Large Installations for Experimental Research

$$X_1$$

SUBMODEL 3

Office Facilities

The instruction staff, the research staff, students engaged in theoretical research, and other personnel concerned with the educational activities of an institution of higher learning require offices in which to carry on all or a part of their duties.

The purpose of Submodel 3 is to determine the office requirements of the professional faculty, by department (division) and rank; of the research staff, by department (division) affiliation; of administrative personnel, by certain groupings according to facilities requirements; of graduate assistants, by department (division); and of those of the secretarial staff connected with instructional and research activities.

Some of these determinations require only the tabulation of information generated in another subsystem or received as new inputs to this particular subsystem. Others depend on information which is generated by applying decision parameters to certain inputs within this submodel.

This section of the report describes the operations which convert the appropriate inputs into the requirements for office facilities. A mathematical model follows this description and there is appended a diagram which shows the sequences of mathematical operations in the model and the use of the decision parameters.

Assumptions

1. Each department (division) has a chairman requiring more extensive office facilities than other instructional staff members.
2. Each project of the research staff has a director requiring the same office facilities as a department (division) chairman.
3. The department (division) chairman has the rank of professor.
4. Professional faculty members engaged in experimental research require offices.
5. Professional faculty members are separated by department (division) and rank to allow the assigning of different office facilities, if desired.
6. Research staff, excluding the directors of projects, have office facilities in the laboratories.
7. Students engaged in experimental research have office facilities in these laboratories.
8. Students engaged in theoretical research may be provided with office facilities, in addition to any library facilities available, in which to perform their research.
9. Library personnel, other than administrative personnel and their secretaries, have office facilities in their work areas and so no separate offices need be provided for them.
10. All other administrative personnel, excluding department (division) chairmen and research project directors already taken into account, can be assigned to one of the groups (1-8) as follows:

A. Groups Requiring Office Facilities Near Instructional Facilities

Group 1 - Personnel requiring extensive office facilities, including facilities for their assistants and for the reception of visitors.

Group 2 - Personnel requiring office facilities, including facilities for their assistants and for the reception of students and visitors.

Group 3 - Personnel requiring office facilities plus facilities for record keeping, for record storage, for interviewing, and the like.

Group 4 - Personnel requiring only office facilities.

Group 5 - Secretaries to groups (1-4) plus secretaries in the secretarial pool, if any.

B. Groups Requiring Office Facilities Near Dormitory and Dining Facilities

Group 6 - Personnel requiring office facilities, including facilities for their assistants and for the reception of visitors.

Group 7 - Personnel requiring only office facilities.

Group 8 - Secretaries to groups (6-7).

Note: These groups are to contain not only the usual administrative personnel, excluding department (division) chairmen and research project directors, but also library, communications, computer, and other similar administrative personnel and their secretaries.

11. Research staff personnel are assigned to a department (division).
12. Each department (division) chairman and each research staff project director, or equivalent title, is provided with a full-time secretary.
13. All ranks of faculty and all graduate teaching assistants are provided with secretarial assistance.
14. All research staff personnel are provided with secretarial assistance.
15. Secretarial assistance for instructional and research staff, excluding department (division) chairmen and research staff project directors, is provided on the basis of one secretary for a specified number of those for whom the service is provided.

Operation 3.1 - Instructional and Research Staff Offices

Input

The inputs to Operation 3.1 are the actual number of professional faculty, by department (division) and rank, from Operation 1.9; the number of project directors in the research staff assigned to each department, from the department profile; and the actual number of graduate teaching assistants in each department (division).

The Operation

This operation consists merely of tabulating, from the inputs, the number of persons, by department (division) and arranged by personnel classification, requiring offices.

Output

The output from Operation 3.1 is the number of persons to be provided with office facilities, arranged by department (division) and personnel classification.

Operation 3.2 - Offices for Students Engaged in Theoretical Research

Input

The inputs to Operation 3.2 are the outputs from Operation 2.2, i.e., the total number of students in each degree program in a given year.

Decision Parameters

The decision parameters for this operation are the percentages of the total number of students in each degree program in a given year who are engaged in theoretical research.

The Operation

This operation consists of multiplying each input by the appropriate decision parameter.

Output

The output from Operation 3.2 is the number of students in each degree program engaged in theoretical research for whom office facilities are to be provided.

Operation 3.3 - Administrative Office Facilities

This operation consists only of tabulating the number of persons in each group, as specified by the institution, of administrative personnel, thus giving the number of administrative personnel requiring office facilities, by groups.

Operation 3.4 - Tabulation of Personnel for Operation 3.5

Input

The inputs to Operation 3.4 are the actual number of professional faculty, by department (division) and rank, from Operations 1.9 and 3.1; the number of project directors in the research staff assigned to each department (division), from Operation 3.1; the number of persons in the research staff, excluding project directors, assigned to each department (division), from the department profile; and the actual number of graduate teaching assistants in each department (division), from Operations 1.8 and 3.1.

The Operation

This operation consists of tabulating, in the form of a matrix, the teaching and research personnel of each department (division), arranged by personnel classification with the research staff separated from the teaching staff, to enable Operation 3.5 to be performed.

Operation 3.5 - Offices Required for Instruction and Research Connected Secretaries

Input

The input to Operation 3.5 is the output of Operation 3.4, i.e., the matrix formulated there.

Decision Parameters

The decision parameter for this operation is the number of secretaries per faculty member and research staff member, excluding department (division) chairmen and research staff project directors.

The Operation

Operation 3.5 consists of multiplying each classification of personnel by the decision parameter, the department (division) chairmen and research staff project directors each having a full-time secretary, and then summing by department (division), with the research staff secretarial needs kept separate by department (division).

Output

The output from this operation is the number of instruction and research connected secretaries requiring office facilities.

Symbols

f_{ir} = the actual number of professional faculty of rank r, $r = 1, 2, 3, 4$, in department (division) i, $i = 1, 2, \ldots, d$, where $r = 1$ refers to professors, $r = 2$ to associate professors, $r = 3$ to assistant professors, and $r = 4$ to instructors (Operation 1.9)

f_{i5} = the number of project directors in the research staff assigned to department (division) i, $i = 1, 2, \ldots, d$ (department profile)

$\underset{6d\times 6}{[F]}$ = the matrix with elements f_{ir}, modified for professors to take account of department (division) chairman, and f_{i5}

f_i'' = the actual number of graduate teaching assistants in department (division) i, $i = 1, 2, \ldots, d$

$\underset{d\times d}{[F_i'']}$ = the diagonal matrix with diagonal elements f_i'' (Operation 1.8)

N_i = the total number of students in degree program i, $i = 1, 2, \ldots, p$, in a given year (Operation 2.2)

p_i''' = the percentage of N_i who are engaged in theoretical research

$\underset{1\times p}{[N_i]}$ = the row vector with components N_i

$[P_i''']$ = the diagonal matrix with diagonal elements p_i''', $i = 1, 2, \ldots, p$

N_{iT} = the number of students in degree program i, $i = 1, 2, \ldots, p$, who are engaged in theoretical research

$\underset{1\times p}{[N_{iT}]}$ = the row vector with components N_{iT}

n_g = the total number of administrative personnel in group g, $g = 1, 2, \ldots, 8$, as the groups are numbered previously

$\underset{1\times 8}{[N_g]}$ = the row vector with components n_g, $g = 1, 2, \ldots, 8$, giving the office requirements for groups (1-8)

f_{i6} = the number of persons in the research staff, excluding project directors, assigned to department (division) i, $i = 1, 2, \ldots, d$ (department profile)

$\underset{6x2d}{[F']}$ = the matrix with elements f_{ir}, f_{i5}, f_{i6}, f_i'

a = the number of secretaries per faculty member and per research staff member, excluding department (division) chairmen and research staff project directors

$\underset{1x6}{[\tilde{A}]}$ = the row vector with components 1, a, a, a, a, a

$[N_s]$ = the row vector with components giving the total instruction and research connected secretaries to be provided with offices, by department (division), i, i = 1, 2, . . ., d

The Models

Operation 3.1 - Instructional and Research Staff Offices

$$\underset{6d\times 6}{[F]} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & f_{11}-1 & 0 & 0 & 0 & 0 \\ 0 & 0 & f_{12} & 0 & 0 & 0 \\ 0 & 0 & 0 & f_{13} & 0 & 0 \\ 0 & 0 & 0 & 0 & f_{14} & 0 \\ 0 & 0 & 0 & 0 & 0 & f_{15} \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & f_{21}-1 & 0 & 0 & 0 & 0 \\ 0 & 0 & f_{22} & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & 0 & 0 & f_{d5} \end{bmatrix}_{6d\times 6}, \quad \text{diag } \underset{d\times d}{[F_i'']} = \text{diag } \underset{d\times d}{[f_1''\ f_2'' \ . \ . \ . \ f_d'']}$$

Note: $\underset{6d\times 6}{[F]}$ is a re-arrangement of the elements of $\underset{d\times 4d}{[F_{iT}]}$ from Submodel 1 with the addition of elements f_{i5}. $[F_i'']$ is from Submodel 1.

Note: If the department (division) chairman is not of rank of professor, the model can be modified easily.

Operation 3.2 - Offices for Students Engaged in Theoretical Research

$$N_i = \sum_{j=1}^{7} N_{ij}, \ i = 1, 2, \ . \ . \ . , \ p$$

$$\underset{1\times p}{[N_{iT}]} = \underset{1\times p}{[N_i]} \times \text{diag } \underset{p\times p}{[P_i''']} = \underset{1\times p}{[N_1\ N_2 \ . \ . \ . \ N_p]} \times \text{diag } \underset{p\times p}{[p_1'''\ p_2''' \ . \ . \ . \ p_p''']}$$

Operation 3.3 - Administrative Office Facilities

$$\underset{1\times 8}{[N_g]} = [n_1\ n_2 \ . \ . \ . n_8]$$

Operation 3.4 - Tabulation of Personnel for Operation 3.5

$$\underset{6\text{x}2d}{[F']} = \underset{6\text{x}2d}{\begin{bmatrix} 1 & 1 & \cdots\cdots & 1 & f_{15} & f_{25} & \cdots\cdots & f_{d5} \\ f_{11}-1 & f_{21}-1 & \cdots\cdots & f_{d1}-1 & f_{16} & f_{26} & \cdots\cdots & f_{d6} \\ f_{12} & f_{22} & \cdots\cdots & f_{d2} & 0 & 0 & \cdots\cdots & 0 \\ f_{13} & f_{23} & \cdots\cdots & f_{d3} & 0 & 0 & \cdots\cdots & 0 \\ f_{14} & f_{24} & \cdots\cdots & f_{d4} & 0 & 0 & \cdots\cdots & 0 \\ f''_{1} & f''_{2} & \cdots\cdots & f_{d} & 0 & 0 & \cdots\cdots & 0 \end{bmatrix}}$$

Operation 3.5 - Offices Required for Instruction and Research Connected Secretaries

$$\underset{1\text{x}6}{[\tilde{A}]} = [1\ a\ a\ a\ a\ a]$$

$$\underset{1\text{x}2d}{[N_s]} = \underset{1\text{x}2d}{[n''_1\ n''_2\ \ldots\ n''_d\ n''_{d+1}\ \ldots\ n''_{2d}]} = \underset{1\text{x}6}{[\tilde{A}]} \times \underset{6\text{x}2d}{[F']}$$

__Note:__ If the department (division) chairman is not always of the rank of professor, the matrix [F'] can be modified suitably.

__Note:__ If the basis for assigning secretarial assistance varies among departments (divisions), Operations 3.4 and 3.5 must be changed to reflect the given basis. Further, it is entirely possible that the number of secretaries assigned per faculty member could vary in relation to the level of faculty. This would simply require establishing different values of (a) for each of the levels rather than assuming a single constant value.

Submodel 4

Library Facilities

The importance of the library facility is sufficiently great to warrant more attention in the planning process than is usually granted. The major failing appears to be the tendency to plan libraries on the basis of an independent estimate of the acquisition rate, rather than on the basis of what is needed to satisfy the requirements of the planned research and instructional programs of the institution. The model developed herein, while not as complete or as readily applied as may be desirable, is based on the concept that library planning must reflect developments within the various instructional and research programs.

Central to this approach is the problem of determining the minimum number of books and journal titles required to establish and support the degree programs of the institution. This determination is made in a manner somewhat similar to one developed by Clapp and Jordan [2] in 1965.

This sub-model is developed in the following functional stages:

A. User Facilities

These include such areas as general reading and study areas, carrels of different types, microviewing, and those other areas in which the primary requirement is the formation of the bases for calculating the number and type of stations needed to serve the users.

B. Active Storage Facilities

These include stacks for books in general, reference works, reserve books, and bound journals; current book and journal display; map and print storage; microfilm storage, including programmed learning and/or self-instruction materials and music tapes; microcard storage; music record storage; newspaper storage and display; slides storage; and any others to meet the institution's needs.

C. Staff Work Facilities

Provision is made for such library services as: acquisitions, bibliography, cataloging, circulation, historical collections, information retrieval and data processing, microprocessing, orders and interlibrary loans, photo reproductions (xerox, etc.), materials preparation, periodicals, receiving and shipping, reference, repair and binding, and music.

Although the library facilities of an educational institution frequently consist of a main library and various school and/or department libraries, such a division has not been made for purposes of this study. Rather, all library facilities have been considered as a single unit regardless of the (possibly diverse) physical locations of the facilities.

This section contains a written description of the methods used in determining the facilities needs in each of the above-mentioned categories. Then the mathematical models for these determinations are presented. Finally, there is a diagram showing the sequence of mathematical operations and the parameters in these operations.

Assumptions

1. Library facilities are classified as user facilities, storage facilities and staff (or service) facilities.
2. The number of library users to be accommodated simultaneously is determined separately for professional faculty, research staff, students, and administrative personnel to allow for different types of study facilities for these groups, if desired.
3. The persons using the library simultaneously are accommodated in a variety of user facilities.
4. All microfilm and microcard material, slides, maps and art prints, and tapes for programmed learning and self-instruction are included in the library holdings.
5. The library collection can include music records and tapes.
6. Music tapes and programmed learning and self-instruction tapes can be grouped with microfilm reels for storage.
7. Only one copy of each issue of journals and newspapers is held in the library collection.
8. Display facilities for current journals are provided in the periodicals room or other facility of the library.
9. A collection of back volumes of journals and newspapers is stored in the library facilities.
10. Back volumes of journals are to be shelved, put on microfilm, or put on microcards whereas back volumes of newspapers are to be shelved or put on microfilm.
11. Storage facilities for documents from government agencies are not included in the model.
12. Secretaries will not use library facilities in general.
13. An estimate can be made of the number of library personnel to be provided with staff work facilities.

14. It is possible to specify the minimum number of books required to establish various degree programs. Furthermore, it is possible to specify the additional number of books required per student in each degree program.
15. Books can be stored by being shelved or by being put on microcards or microfilm.

A. User Facilities - Operations 4.1 - 4.09

Operation 4.1 - Total Number of Professional Faculty

Input

The input to Operation 4.1 is the output from Operation 1.8, i.e., the actual number of professional faculty in each department (division).

The Operation

This operation consists of adding the number of professional faculty in each department (division).

Output

The output from Operation 4.1 is the total number of professional faculty in the institution.

Operation 4.2 - Professional Faculty Library Users

Input

The input to Operation 4.2 is the output from Operation 4.1, the total number of professional faculty in the institution.

Decision Parameter

The decision parameter for this operation is the percentage of the total number of professional faculty to be provided with library facilities to be used simultaneously.

The Operation

Operation 4.2 consists of multiplying the total number of professional faculty in the institution by the decision parameter.

Output

The output from this operation is the number of the professional faculty to use library facilities simultaneously.

Operation 4.3 - Total Research Staff by Department (Division)

Input

The inputs to Operation 4.3 are the total number of project directors and the number of other persons in the research staff assigned to each department (division).

The Operation

This operation consists of adding the two inputs to Operation 4.3 for each department (division).

Output

The output from Operation 4.3 is the total number of research staff for each department (division).

Operation 4.4 - Total Institution Research Staff

Input

The input to Operation 4.4 is the output from Operation 4.3, the total number of research staff for each department (division).

The Operation

This operation sums the total number of research staff for all departments (division).

Output

The output from this operation is the total number of research staff at the Institution.

Operation 4.5 - Research Staff Library Users

Input

The input to Operation 4.5 is the output from Operation 4.4, the total number of research staff at the institution.

Decision Parameter

The decision parameter for Operation 4.5 is the percentage of the total number of research staff to be provided with library facilities to be used simultaneously.

The Operation

This operation consists of multiplying the total number of research staff at the institution by the decision parameter.

Output

The output from Operation 4.5 is the number of the research staff to use library facilities simultaneously.

Operation 4.6 - Total Administrative Personnel in Certain Groups

Input

The inputs to Operation 4.6 are the outputs from Operation 3.3, omitting secretaries, i.e., the number of administrative personnel in groups (1-4), 6, 7.

The Operation

This operation consists of adding the inputs, the number of administrative personnel in groups (1-4), 6, 7.

Output

The output from Operation 4.6 is the total number of administrative personnel in groups (1-4), 6, 7.

Operation 4.7 - Administrative Library Users

Input

The input to Operation 4.7 is the output from Operation 4.6, the total number of administrative personnel in groups (1-4), 6, 7.

Decision Parameter

The decision parameter for this operation is the percentage of the total administrative personnel in groups (1-4), 6, 7, to be provided with library facilities to be used simultaneously.

The Operation

This operation consists of multiplying the input to this operation by the decision parameter.

The Output

The output from Operation 4.7 is the total number of administrative personnel to use library facilities simultaneously.

Operation 4.8 - Total Student Enrollment

Input

The input to Operation 4.8 is the same as the input to Operation 1.1, the number of students in each degree program at each academic level, in a given year.

The Operation

This operation consists in summing the number of students in each degree program at each academic level, in a given year.

Output

The output from Operation 4.8 is the total number of students enrolled at the institution.

Operation 4.9 - Student Library Users

Input

The input to Operation 4.9 is the output from Operation 4.8, the total number of students enrolled at the institution.

Decision Parameter

The decision parameter for this operation is the percentage of the total number of students, enrolled at the institution, to be accommodated in the library simultaneously.

The Operation

Operation 4.9 consists of multiplying the total number of students, enrolled at the institution, by the decision parameter.

Output

The output from Operation 4.9 is the total number of students, enrolled at the institution, to be accommodated in the library simultaneously.

B. Active Storage Facilities

I. Minimum Required Number of Books and Journals - Operations 4.10 - 4.25

Operation 4.10 - Vector Formation for Operation 4.11

Input

The inputs to Operation 4.10 are new inputs as follow: the minimum number of books required to establish each degree program, the number of undergraduate students in honors or independent study programs in each degree program, the number of students enrolled for a master's degree in each degree program, the number of students enrolled for a doctor's degree in each degree program, and the output from Operation 3.2, the total number of students in each degree program.

The Operation

This operation merely arranges the inputs in a convenient form for the next operation.

Operation 4.11 - Total Books Required by Degree Program

Input

The input to Operation 4.11 is the output from Operation 4.10, i.e., the inputs to Operation 4.10 as arranged for performance of this operation.

Decision Parameters

The decision parameters for this operation are the minimum number of books required to establish each degree program, the number of books per student in each degree program, the number of books per undergraduate student in honors or independent study programs in each degree program, the number of books per student enrolled for a master's degree in each degree program, and the number of books per student enrolled for a doctor's degree in each degree program.

The Operation

Operation 4.11 consists of adding to the minimum number of books required to establish each degree program the products of the number of students in each degree program, the number of undergraduate students in honors or independent study programs in each degree program, the number of students enrolled for a master's degree in each degree program, and the number of students enrolled for a doctor's degree program by the appropriate decision parameter specifying the number of books per student in each of these groups.

Output

The output from Operation 4.11 is the number of books required for each degree program.

Operation 4.12 - Total Books Required for All Degree Programs

Input

The inputs to Operation 4.12 are the outputs from Operation 4.11, the number of books required for each degree program. There are as many inputs to Operation 4.12 as there are degree programs.

The Operation

This operation sums, over all degree programs, the number of books required for each degree program.

Output

The output from Operation 4.12 is the total number of books required for all degree programs.

Operation 4.13 - Total Professional Faculty and Research Staff by Department (Divisio

Input

The inputs to Operation 4.13 are the outputs from Operation 1.8 as used in Operation 3.4, i.e., the actual number of professional faculty in each department (division), the total number of research directors assigned to each department (division), and the number of other persons in the research staff assigned to each department (division).

The Operation

This operation merely adds the inputs to the operation.

Output

The output from Operation 4.13 is the total number of professional faculty and research staff assigned to each department (division).

Operation 4.14 - Books Required for Professional Faculty and Research Staff By Department (Division)

Input

The input to Operation 4.14 is the output from Operation 4.13, the total number of professional faculty and research staff assigned to each department (division).

Decision Parameter

The decision parameter for Operation 4.14 is the number of books per professional faculty and research staff member in each department (division).

The Operation

This operation multiplies the input to Operation 4.14 by the decision parameter for the operation.

Output

The output from Operation 4.14 is the number of books required for the professional faculty and research staff of each department (division).

Operation 4.15 - Total Number of Books Required for All Professional Faculty and Research Staff

Input

The input to Operation 4.15 is the output from Operation 4.14, the number of books required for the professional faculty and research staff of each department (division).

The Operation

This operation sums the input over all departments (divisions).

Output

The output from Operation 4.15 is the total number of books required by the professional faculty and research staff at the institution.

Operation 4.16 - Total Administrative Staff, Omitting Secretaries

Input

The inputs to Operation 4.16 are several of the outputs of Operation 3.3, i.e., the total number of administrative personnel in groups (1-4), 6, 7 as there indicated.

The Operation

This operation adds the several inputs to Operation 4.16.

Output

The output from Operation 4.16 is the total number of administrative personnel, omitting secretaries.

Operation 4.17 - Books Required for Administrative Personnel

Input

The input to Operation 4.17 is the output from Operation 4.16, the total number of administrative personnel, omitting secretaries.

Decision Parameter

The decision parameter for this operation is the number of books per administrative personnel member, omitting secretaries.

The Operation

Operation 4.17 consists of multiplication of the input to this operation by the decision parameter.

Output

The output from Operation 4.17 is the total number of books required for the administrative personnel, omitting secretaries.

Operation 4.18 - Total Books Required

Input

The inputs to Operation 4.18 are the outputs from Operations 4.12, 4.15 and 4.17, i.e. the total number of books required respectively for all degree programs, for the professional faculty and research staff, and for the administrative personnel, omitting secretaries.

The Operation

Operation 4.18 consists of adding the three inputs to the operation.

Output

The output from Operation 4.18 is the minimum total number of books required for the educational, research, and administrative activities of the institution.

Operations 4.19 - 4.25 - Total Journal Titles Required

These operations for journal titles almost parallel those for books, the words "journal titles" being substituted for the word "books," as described previously for Operations 4.10 - 4.18. Consequently, descriptions of the operations are omitted.

Output

The output from Operation 4.25 is the minimum total number of journal titles required for the educational, research, and administrative activities of the institution.

II. Storage Units for Library Holdings - Operations 4.26 - 4.39

Operation 4.26 - Number of Books to be Shelved, to be put on Microfilm and Microcards

Input

The input to Operation 4.26 is the output from Operation 4.18, the minimum total number of books required for the educational, research, and administrative activities of the institution.

Decision Parameters

The decision parameters for this operation are the percentage of the minimum total number of books to be shelved, the percentage to be put on microfilm, and the percentage to be put on microcards.

The Operation

This operation consists of multiplying the input, the minimum total number of books, by each of these decision parameters.

Output

The outputs from Operation 4.26 are the number of books to be shelved, the number to be put on microfilm, and the number to be put on microcards.

Operation 4.27 - Total Journal Volumes Deposited in Library

Input

The input to Operation 4.27 is the output from Operation 4.25, the minimum total number of journal titles required for the educational, research, and administrative activities of the institution.

Decision Parameter

The decision parameter for Operation 4.27 is the average number of journal volumes per journal title to be deposited in the library.

The Operation

This operation consists of multiplying the input, the minimum total number of journal titles, by the decision parameter.

Output

The output from Operation 4.27 is the total number of journal volumes to be deposited in the library.

Operation 4.28 - Number of Journal Volumes to be Shelved; Put on Microfilm and Microcards

Input

The input to Operation 4.28 is the output from Operation 4.27, the total number of journal volumves to be deposited in the library.

Decision Parameters

The decision parameters for Operation 4.28 are the percentage of the total number of journal volumes to be shelved, the percentage to be put on microfilm, and the percentage to be put on microcards.

The Operation

This operation consists of multiplying the input, the total number of journal volumes to be deposited in the library, by each of the three decision parameters.

Output

The outputs from Operation 4.28 are the number of journal volumes to be shelved, the number to be put on microfilm, and the number to be put on microcards.

Operation 4.29 - Total Newspaper Volumes to be Deposited in Library

Input

The input to Operation 4.29 is a new input, namely the total number of newspaper titles obtained for library use.

Decision Parameter

The decision parameter for Operation 4.29 is the average number of newspaper volumes per newspaper title to be deposited in the library.

The Operation

This operation consists of multiplying the input, the total number of newspaper titles, by the decision parameter.

Output

The output from Operation 4.29 is the total number of newspaper volumes to be deposited in the library.

Operation 4.30 - Number of Newspaper Volumes to be Shelved and to be Put on Microfilm

Input

The input to Operation 4.30 is the output from Operation 4.29, the total number of newspaper volumes to be deposited in the library.

Decision Parameters

The decision parameters for this operation are the percentage of the total number of newspaper volumes to be shelved and the percentage to be put on microfilm.

The Operation

This operation consists of multiplying the input, the total number of newspaper volumes, by the two decision parameters.

Output

The outputs from Operation 4.30 are the number of newspaper volumes to be shelved and the number to be put on microfilm.

Operation 4.31 - Number of Programmed Learning and/or Self Instruction Tapes and Music Tapes to be Deposited in the Library

Input

The input to Operation 4.31 is the output from Operation 2.2, the student enrollment in each degree program.

Decision Parameters

The decision parameters for this operation are the number of programmed learning and/or self-instruction tapes per student in each degree program and the number of music tapes per student in each degree program.

The Operation

Operation 4.31 consists of multiplying the number of students in each degree program by each of the two parameters and summing the products separately for programmed learning and/or self instruction tapes and music tapes.

Output

The two outputs from Operation 4.31 are the total number of programmed learning and/or self-instruction tapes and the total number of music tapes to be held in the library.

Operation 4.32 - Formation of Row Vector for Operation 4.33

Input

The inputs to Operation 4.32 are the number of books to be put on microfilm, from Operation 4.26; the number of journal volumes to be put on microfilm, from Operation 4.28; and the number of newspaper volumes to be put on microfilm, from Operation 4.30.

The Operation

Operation 4.32 merely arranges the inputs in a form suited to the next operation.

Operation 4.33 - Required Microfilm Reels

Input

The inputs to Operation 4.33 are the inputs to Operation 4.32, as arranged by that operation.

Decision Parameters

The decision parameters for Operation 4.33 are the average number of microfilm reels per book, the average number of microfilm reels per journal volume, and the average number of microfilm reels per newspaper volume.

The Operation

This operation consists of multiplying each of the inputs by the appropriate one of the three decision parameters and summing the resulting products.

Output

The output from Operation 4.33 is the total number of microfilm reels required for books, journal volumes, and newspaper volumes to be held in the library.

Operation 4.34 - Total Number of Tapes and Microfilm Reels to be Stored

Input

The inputs to Operation 4.34 are the two outputs from Operation 4.31 and the output from Operation 4.33

The Operation

This operation consists of adding the three inputs to the operation.

Output

The output from Operation 4.34 is the total number of programmed learning and/or self-instruction tapes; music tapes; and microfilm reels required for books, journal volumes, and newspaper volumes to be held in the library.

Operation 4.35 - Formation of Row Vector for Operation 4.36

Input

The inputs to Operation 4.35 are the number of books to be put on microcards, from Operation 4.26, and the number of journal volumes to be put on microcards, from Operation 4.28.

The Operation

This operation is only an arrangement of two inputs to facilitate the next operation.

Operation 4.36 - Total Microcards to be Stored

Input

The inputs to Operation 4.36 are the inputs to Operation 4.35, as arranged by that operation.

Decision Parameters

The decision parameters for this operation are the average number of microcards per book and the average number of microcards per journal volume.

The Operation

Operation 4.36 consists of multiplying each of the two inputs by the appropriate decision parameter and adding the two products so formed.

Output

The output from Operation 4.36 is the total number of microcards required for books and journal volumes to be held in the library.

Operation 4.37 - Number of Slides, Maps and/or Art Prints, and Music Records to be Held in the Library

Input

The input to Operation 4.37 is the output from Operation 2.2, the student enrollment in each degree program, as in Operation 4.31.

Decision Parameters

The decision parameters for this operation are the number of slides per student in each degree program, the number of maps and/or art prints per student in each degree program, and the number of music records per student in each degree program.

The Operation

This operation consists of multiplying the input, the student enrollment in each degree program, by each of the decision parameters in turn and adding separately the products for slides, maps and/or art prints and music records.

Output

The three separate outputs from Operation 4.37 are the total number of slides, the total number of maps and/or art prints, and the total number of music records to be held in the library.

Operation 4.38 - Formation of Row Vector for Operation 4.39

Input

There are eight inputs to Operation 4.38, namely, the number of books to be shelved, from Operation 4.26; the number of journal volumes to be shelved, from Operation 4.28; the number of newspaper volumes to be shelved, from Operation 4.30; the total number of microfilm reels, programmed learning and/or self-instruction tapes, and music tapes, from Operation 4.34; the total number of microcards for books and journal volumes, from Operation 4.36; the total number of slides, the total number of maps and/or art prints, and the total number of music records, the last three from Operation 4.37.

The Operation

This operation merely arranges the above eight inputs in a convenient form for the next operation.

Operation 4.39 - Storage Units Required

Input

The inputs to Operation 4.39 are the inputs to Operation 4.38, as arranged in that operation.

Decision Parameters

There are eight parameters for Operation 4.39, one for each of the eight inputs. These are the number of books per shelving units, the number of bound journal volumes per shelving unit; the number of bound newspaper volumes per shelving unit; the number of microfilm reels, programmed learning and/or self-instruction tapes, and music tapes per storage unit; the number of microcards per storage unit; the number of slides per storage unit; the number of maps and/or art prints per storage unit; and the number of music records per storage unit.

The Operation

This operation consists of dividing each of the eight inputs by the appropriate one of the eight decision parameters.

Output

The outputs from Operation 4.39 are eight in number, namely, the number of storage units for each of books; bound journal volumes; bound newspaper volumes; microfilm reels, programmed learning and/or self-instruction tapes, and music tapes; microcards; slides; maps and/or art prints; and music records.

C. Staff Work Facilities

A representative list library personnel, requiring work facilities for staff members, has been given previously. The number of staff members involved depends on the facilities installed or planned for the library and the volume of work to be done in each facility. Consequently, this number of staff members is not readily quantifiable. Nevertheless, each institution should be able to estimate rather closely the number of persons involved.

The Operation

An estimate of the number of persons to be provided with staff work facilities.

Symbols

A. User Facilities

f'_i = the actual number of professional faculty in department (division) i, $i = 1, 2, \ldots, d$ (from Operation 1.8)

F_t = the total number of professional faculty at the institution

r_f = the percentage of F_t to be provided with library facilities to be used simultaneously

F_L = the number of professional faculty to use library facilities simultaneously

f_{i5} = the number of project directors in the research staff assigned to department (division) i, $i = 1, 2, \ldots, d$ (from Operation 3.1)

f_{i6} = the number of persons in the research staff, excluding project directors, assigned to department (division) i, $i = 1, 2, \ldots, d$, (from department profiles)

N_R = the total number of research staff at the institution

r_R = the percentage of N_R to be provided with library facilities to be used simultaneously

R_L = the number of research staff to use library facilities simultaneously

n_g = the total number of administrative personnel in group g, $g = 1, 2, \ldots, 8$, as the groups are numbered previously (from Operation 3.3)

N_G = the total number of administrative personnel in groups (1-8), omitting secretaries, at the institution.

r_G = the percentage of N_G to be provided with library facilities to be used simultaneously

A_L = the number of administrative personnel to use library facilities simultaneously

N_{ij} = the number of students in degree program i at academic level j, $i = 1, 2, \ldots, p$, $j = 1, 2, \ldots, 7$, in a given year (as in Operation 1.1)

N_T = the total number of students enrolled in the institution

rs = the percentage of N_T to be accommodated in the library simultaneously

N_L = the total number of students to be accommodated in the library simultaneously

B. Active Storage Facilities

b_p = the minimum number of books required to establish degree program p, p = 1, 2, . . ., p (new input)

p = the number of degree programs

N_p = the total number of students in degree program p, p = 1, 2, . . ., p (same as N_i from Operation 3.2)

H_p = the number of undergraduate students in honors or independent study programs in degree program p, p = 1, 2, . . ., p (new input)

M_p = the number of students enrolled for a master's degree in degree program p, p = 1, 2, . . ., p (new input)

D_p = the number of students enrolled for a doctor's degree in degree program p, p = 1, 2, . . ., p (new input)

v_p = the number of books per student in degree program p, p = 1, 2, . . ., p

v'_p = the number of books per undergraduate student in honors or independent study programs in degrees program p, p = 1, 2, . . ., p

v''_p = the number of books per student enrolled for a master's degree in degree program p, p = 1, 2, . . ., p

v'''_p = the number of books per student enrolled for a doctor's degree in degree program p, p = 1, 2, . . ., p

F''_i = the total number of professional faculty and research staff in or assigned to department (division) i, i = 1, 2, . . ., d

v_i = the number of books per individual included in F''_i

$n_1, n_2, n_3, n_4, n_6, n_7$ = the number of administrative personnel in groups 1, 2, 3, 4, 6, 7, (from Operation 3.3)

N_a = the total number of administrative personnel in groups 1, 2, 3, 4, 6, 7

v_a = the number of books per person in N_a

j_p = the minimum number of journal titles required to establish degree program p, $p = 1, 2, \ldots, p$ (new input)

V_a = the number of journal titles per person in N_a

V_i = the number of journal titles per individual included in F_i'', $i = 1, 2, \ldots, d$

V_p = the number of journal titles per student in degree program p, $p = 1, 2, \ldots, p$

V'_p = the number of journal titles per undergraduate student in honors or independent study program in degree program p, $p = 1, 2, \ldots, p$

V''_p = the number of journal titles per student enrolled for a master's degree in degree program p, $p = 1, 2, \ldots, p$

V'''_p = the number of journal titles per student enrolled for a doctor's degree in degree program p, $p = 1, 2, \ldots, p$

J = the total number of journal titles required for all degree programs and staff (from Operation 4.25)

B = the total number of books required for all degree programs and staff (from Operation 4.18)

P' = the number of newspaper titles obtained for library use (new input)

k = the average number of back journal volumes per journal title to be deposited in the library

k' = the average number of back newspaper volumes per newspaper title to be deposited in the library

p_1 = the percentage of B to be shelved

p_2 = the percentage of B to be put on microfilm

p_3 = the percentage of B to be put on microcards

p'_1 = the percentage of the total number of journal volumes to be shelved

p'_2 = the percentage of the total number of journal volumes to be put on microfilm

p'_3 = the percentage of the total number of journal volumes to be put on microcards

p''_1 = the percentage of the total number of newspaper volumes to be shelved

p''_2 = the percentage of the total number of newspaper volumes to be put on microfilm

B_1 = the total number of books to be shelved

B_2 = the total number of books to be put on microfilm

B_3 = the total number of books to be put on microcards

J_1 = the total number of journal volumes to be shelved

J_2 = the total number of journal volumes to be put on microfilm

J_3 = the total number of journal volumes to be put on microcards

p'_1 = the total number of newspaper volumes to be shelved

p'_2 = the total number of newspaper volumes to be put on microfilm

N_i = the total number of students in degree program i, $i = 1, 2, . . ., p$ (from Operation 3.2)

T_i = the number of programmed learning and/or self-instruction tapes provided per student in degree program i, $i = 1, 2, . . ., p$

T'_i = the number of music tapes provided per student in degree program i, $i = 1, 2, . . ., p$

T = the total number of programmed learning and/or self-instruction tapes to be stored

T' = the total number of music tapes to be stored

m_1 = the average number of microfilm reels per book

m'_1 = the average number of microfilm reels per journal volume

m''_1 = the average number of microfilm reels per newspaper volume

M'_1 = the total number of microfilm reels for books, journal volumes and newspaper volumes

M'_2 = the total number of microfilm reels for books, journal volumes, newspaper volumes, plus programmed learning and/or self-instruction tapes and music tapes to be stored

m_2 = the average number of microcards per book

m'_2 = the average number of microcards per journal volume

M'_3 = the total number of microcards for books and journal volumes to be stored

s_i = the number of slides per student in degree program i, $i = 1, 2, \ldots, p$

m'''_i = the number of maps and/or art prints per student in degree program i, $i = 1, 2, \ldots, p$

m^{iv}_i = the number of music records per student in degree program i, $i = 1, 2, \ldots, p$

S'' = the total number of slides to be stored

M'_4 = the total number of maps and/or art prints to be stored

M'_5 = the total number of music records to be stored

u_1 = the number of books per shelving unit

u_2 = the number of bound journal volumes per shelving unit

u_3 = the number of bound newspaper volumes per shelving unit

u_4 = the number of microfilm reels and tapes per storage unit

u_5 = the number of microcards per storage unit

u_6 = the number of slides per storage unit

u_7 = the number of maps and/or art prints per storage unit

u_8 = the number of music records per storage unit

U_1 = the number of shelving units for books

U_2 = the number of shelving units for bound journal volumes

U_3 = the number of shelving units for bound newspaper volumes

U_4 = the number of microfilm and tape storage units

U_5 = the number of microcard storage units

U_6 = the number of storage units for slides

U_7 = the number of storage units for maps and/or art prints

U_8 = the number of storage units for music records

C. Staff Work Facilities

N_w = the number of library staff to be provided with work facilities

The Models

A. User Facilities

Operation 4.1 - Total Number of Professional Faculty

$$F_T = \sum_{i=1}^{d} f'_i$$

Operation 4.2 - Professional Faculty Library Users

$$F_L = F_T \times r_f$$

Operation 4.3 - Total Research Staff by Department (Division)

Add: $f_{i5} + f_{i6}$

Operation 4.4 - Total Institution Research Staff

$$N_R = \sum_{i=1}^{d} (f_{i5} + f_{i6})$$

Operation 4.5 - Research Staff Library Users

$$R_L = N_R \times r_R$$

Operation 4.6 - Total Administrative Personnel in Certain Groups

$$N_G = n_1 + n_2 + n_3 + n_4 + n_6 + n_7$$

Operation 4.7 - Administrative Library Users

$$A_L = N_G \times r_G$$

Operation 4.8 - Total Student Enrollment

$$N_T = \sum_{i=1}^{p} \sum_{j=1}^{7} N_{ij}$$

Operation 4.9 - Student Library Users

$$N_L = N_T \times r_s$$

Note: If private study facilities such as closed carrels are provided for any groups, for example faculty and research staff, these must be counted as part of the simultaneous occupancy for which provision is to be made.

Note: It is possible to distribute the simultaneous occupancy over the various types of facility such as bibliography, carrels, conference, historical collections, map and art prints, microviewing, music, periodical, projection, reference, seminar, typing, and the like, by multiplying the outputs F_L, R_L, A_L, and N_L by appropriate matrices with elements which are the percentages of these outputs to be accommodated in each facility.

B. Active Storage Facilities

I. Minimum Required Number of Books and Journals - Operation 4.10-4.25

Operations 4.10 - 4.18

$$B = \sum_{p=1}^{p} \{ [b_p \ N_p \ H_p \ M_p \ D_p] \times [1 \ v_p \ v'_p \ v''_p \ v'''_p]^T \} + \sum_{i=1}^{d} F''_i \ v_i + N_a \ v_a$$

Operations 4.19 - 4.25

$$J = \sum_{p=1}^{p} \{ [j_p \ N_p \ H_p \ M_p \ D_p] \times [1 \ V_p \ V'_p \ V''_p \ V'''_p]^T \} + \sum_{i=1}^{d} F''_i \ V_i + N_a \ V_a$$

Note: These models follow the scheme set forth in Clapp, V. W. and Jordan, R. T. [2] except that here the computation is made by degree program, department (division), and administration rather than for the entire institution at once.

II. Storage Units for Library Holdings - Operations 4.26 - 4.39

Operation 4.26 - Number of Books to be Shelved, to be Put on Microfilm and Microcards

$$\underset{1\mathrm{x}3}{[B_1 \ B_2 \ B_3]} = B \ \underset{1\mathrm{x}3}{[p_1 \ p_2 \ p_3]}$$

Operations 4.27 and 4.28 - Number of Journal Volumes to be Shelved; Put on Microfilm and Microcards

$$\underset{1\mathrm{x}3}{[J_1 \ J_2 \ J_3]} = k \ J \ \underset{1\mathrm{x}3}{[p'_1 \ p'_2 \ p'_3]}$$

Operations 4.29 - 4.30 - Number of Newspaper Volumes to be Shelved and to be Put on Microfilm

$$\underset{1x2}{[P'_1 \; P'_2]} = k' \; P' \; \underset{1x2}{[p''_1 \; p''_2]}$$

Operation 4.31 - Number of Programmed Learning and/or Self Instruction Tapes and Music Tapes to be Deposited in the Library.

$$\underset{1x2}{[T \; T']} = \underset{1xp}{[N_i]} \; x \; \underset{px2}{\begin{bmatrix} T_1 & T'_1 \\ T_2 & T'_2 \\ \cdots & \cdots \\ T_p & T'_p \end{bmatrix}}$$

Operation 4.32 - Formation of Row Vector for Operation 4.33

Form row vector $\underset{1x3}{[B_2 \; J_2 \; P'_2]}$

Operation 4.33 - Required Microfilm Reels

$$\underset{1x1}{[M'_1]} = \underset{1x3}{[B_2 \; J_2 \; P'_2]} \; x \; \underset{3x1}{[m_1 \; m'_1 \; m''_1]^T}$$

Operation 4.34 - Total Number of Tapes and Microfilm Reels to be Stored

$$M'_2 = M'_1 + T + T'$$

Operation 4.35 - Formation of Row Vector for Operation 4.36

Form row vector $\underset{1x2}{[B_3 \; J_3]}$

Operation 4.36 - Total Microcards to be Stored

$$\underset{1x1}{[M'_3]} = \underset{1x2}{[B_3 \; J_3]} \; x \; \underset{2x1}{[m_2 \; m'_2]^T}$$

Operation 4.37 - Number of Slides, Maps and/or Art Prints, and Music Records to be Held in the Library

$$\underset{1x3}{[S'' \; M'_4 \; M'_5]} = \underset{1xp}{[N_i]} \; x \; \underset{px3}{\begin{bmatrix} S_1 & m'''_1 & m^{iv}_1 \\ S_2 & m'''_2 & m^{iv}_2 \\ \cdots & \cdots & \cdots \\ S_p & m'''_p & m^{iv}_p \end{bmatrix}}$$

Operation 4.38 - Formation of Row Vector for Operation 4.39

Form row vector $[B_1\ J_1\ P_1'\ M_2'\ M_3'\ S''\ M_4'\ M_5']$

Operation 4.39 - Storage Units Required

$$\underset{\mathrm{1x8}}{[U_1\ U_2\ U_3\ U_4\ U_5\ U_6\ U_7\ U_8]} = \underset{\mathrm{1x8}}{[B_1\ J_1\ P_1'\ M_2'\ M_3'\ S''\ M_4'\ M_5']}\ \mathrm{x}\ \mathrm{diag} \underset{\mathrm{8x8}}{\begin{bmatrix} \frac{1}{u_1} & \frac{1}{u_2} & \cdots & \frac{1}{u_8} \end{bmatrix}}$$

C. Staff Work Facilities

Operation 4.40

N_w

Submodels 5 and 6

Living and Dining Facilities

Student living facilities and dining facilities are considered together because they are both non-academic facilities which are necessitated by the presence of a student body rather than by the specific academic interests of sub-groups within the student body. Consequently there are two problems requiring solution: (1) given a student enrollment by degree program and academic level, to determine the number of students according to sex, marital status, and academic level (where relevant to an institution's housing policies) for whom living facilities are to be provided, and (2) given a student enrollment by degree program and academic level, a professional faculty, a reseach staff, an administrative staff, an instruction and research connected secretarial staff, and a service staff, to determine the number of persons for whom dining facilities are to be provided.

Both of these sub-models require the use of specified decision parameters, the numerical values of which reflect past experience and/or future expectations, requirements, or preferences.

This section of the report describes, in words, the operations and decision parameters required for the solution of the two problems. This is followed by mathematical models of the operations and by a diagram showing the sequence of the mathematical operations and the use of the decision parameters.

Assumptions - Submodel 5; Student Living Facilities

For purposes of developing this model, the student body is grouped into the following five categories:

1. single male undergraduate students
2. single female undergraduate students
3. single male graduate students
4. single female graduate students, and
5. married students

Note: The policies in force at any particular institution may vary considerably from the situation assumed in the above listing of categories. These various policies can be accommodated by either deleting categories (e.g. by not differentiating between graduate and undergraduate students and using only single male and single female categories) or by adding categories (e.g. by subdividing the undergraduates by level or by academic or social interests). The only requirements imposed are that the categories must be mutually exclusive (i.e. no student can be counted twice) and that, once established, they must be used consistently.

Operation 5.1 - Number of Students by Category

Input

The input to Operation 5.1 is the total number of students enrolled at the institution (from Operation 4.8).

Decision Parameters

The decision parameters for this operation are the distribution, in percentage terms, of the total number of students among the several categories (i.e., the percentage of the students who are 1) single male undergraduate, 2) single female undergraduate, 3) single male graduate, 4) single female graduate, and 5) married).

The Operation

The operation consists of multiplying the total number of students by the percentage of these students expected to be in each category.

Output

The outputs from Operation 5.1 are the numbers of students in each of the five categories listed previously.

Operation 5.2 - Number of Non-Commuting Students by Category

Input

The inputs are the outputs from the previous operation, the number of students in each of the categories.

Decision Parameters

The decision parameters for this operation are the percentages of the students in each category who are expected to be non-commuting students (i.e. students who do not live at home).

The Operation

Operation 5.2 consists of multiplying the total number of students in each category by the percentage of students in each category expected to be non-commuters.

Output

The outputs from this operation are the numbers of non-commuting students in each of the categories. This output indicates the maximum number of students, by category, who could require on-campus housing facilities.

Operation 5.3 - Number of Students to be Housed

Input

The inputs to Operation 5.3 are the outputs from Operation 5.2, the number of non-commuting students in each of the five categories.

Decision Parameters

The decision parameters for this operation are the percentages of the number of non-commuting students, in each of the five categories, for whom it is planned to provide living facilities.

Output

The outputs from Operation 5.3 are the number of students, in each of the five categories, to be housed.

Symbols for Submodel 5

N_T = the total number of students enrolled at the institution (from Operation 4.8)

r_q = the percentage of N_T in category q, $q = 1, 2, \ldots, 5$ (see assumptions for definitions of these categories)

N'_q = the number of students in category q, $q = 1, 2, \ldots, 5$

r'_q = the percentage of N'_q who are non-commuting students, $q = 1, 2, \ldots, 5$

N''_q = the number of non-commuting students in category q, $q = 1, 2, \ldots, 5$

P_q = the percentage of N''_q for whom it is planned to provide living facilities, $q = 1, 2, \ldots, 5$

n'_q = the number of students in category q to be housed, $q = 1, 2, \ldots, 5$

$\underset{1x5}{[N]}$ = the row vector with components n'_q

Models for Submodel 5

Operation 5.1 - Number of Students by Category

$$\underset{1x5}{[N'_q]} = [N'_1 \quad N'_2 \quad . \ . \ . \quad N'_5] = N_T \underset{1x5}{[r_1 \quad r_2 \quad . \ . \ . \quad r_5]}$$

Operation 5.2 - Number of Non-Commuting Students by Category

$$\underset{1x5}{[N''_q]} = [N''_1 \quad N''_2 \quad . \ . \ . \quad N''_5] = \underset{1x5}{[N'_q]} \ x \ \mathrm{diag} \underset{5x5}{[r'_1 \quad r'_2 \quad . \ . \ . \quad r'_5]}$$

Operation 5.3 - Number of Students to be Housed by Category

$$\underset{1x5}{[N]} = [n'_1 \ n'_2 \ n'_3 \ n'_4 \ n'_5] = \underset{1x5}{[N''_q]} \ x \ \mathrm{diag} \underset{5x5}{[p_1 p_2 p_3 p_4 p_5]}$$

Assumptions - Submodel 6; Dining Facilities

1. Students housed in certain living facilities may be required to take meals in the institution's dining facilities.
2. Students not required to take meals in the dining facilities may take their meals there.
3. Faculty, research staff, and other personnel may take meals in the dining facilities.
4. Dining facilities must be adequate to accommodate the maximum number of diners to be served at any one meal.

Operation 6.1 - Total Number of Students to be Housed

Input

The inputs to Operation 6.1 are the outputs from Operation 5.3, the number of students to be housed, by category.

The Operation

Operation 6.1 consists of adding the number of students in each of the inputs.

Output

The output from Operation 6.1 is the total number of students to be housed.

Operation 6.2 - Total Number of Non-Resident Students

Input

The inputs to Operation 6.2 are the total number of students enrolled, from Operation 4.8, and the output from Operation 6.1, the total number of students to be housed.

The Operation

This operation consists of subtracting the total number of students to be housed from the total number of students enrolled.

Output

The output from Operation 6.2 is the number of non-resident students at the institution.

Operation 6.3 - Total Number of Administrative Personnel

Input

The inputs to Operation 6.3 are the numbers in each of groups (1-8), as previously listed, from Operation 3.3.

The Operation

This operation consists of adding the number of administrative personnel in each of groups (1-8).

Output

The output from Operation 6.3 is the total number of administrative personnel in all eight groups.

Operation 6.4 - Total Number of Instructional and Research Connected Secretaries

Input

The inputs to Operation 6.4 are the number of instruction connected secretaries for professional faculty, by rank; and for graduate teaching assistants and the number of research connected secretaries; by departments (division) (from Operation 3.5).

The Operation

This operation consists of adding all the inputs to Operation 6.4.

Output

The output from Operation 6.4 is the total number of instruction and research connected secretaries.

Operation 6.5 - Formation of Row Vector for Operation 6.6

Input

The inputs to Operation 6.5 are eight in number as follow: the total number of non-resident students, from Operation 6.2; the total number of resident students from Operation 6.1; the total number of professional faculty at the institution, from Operation 4.1; the total number of research staff at the institution, from Operation 4.4; the total number of administrative personnel, from Operation 6.3; the total number of instruction and research connected secretaries, from Operation 6.4; the number of library staff to be provided with work facilities, from Operation 4.40; and the total number of all types of service employees, a new input.

The Operation

This operation is merely an arrangement of the inputs.

Output

The output from Operation 6.5 is a vector arrangement of the inputs for performance of the next operation.

Operation 6.6 - Maximum Number to be Provided with Dining Facilities

Input

The input to Operation 6.6 is the output from Operation 6.5, the arranging of the inputs to Operation 6.5 in a vector form suitable for use in this operation.

Decision Parameters

The decision parameters for this operation are the percentages of each of the inputs to take meals in dining facilities at the meal with the maximum number of diners.

The Operation

This operation consists of multiplying each of the inputs by the appropriate decision parameter and summing the products so formed.

Output

The output from Operation 6.6 is the maximum number for whom dining facilities are to be provided.

Symbols for Sub-Model 6

N_T = the total number of students enrolled at the institution (from Operation 4.8)

n'_q = the number of students in category q, q= 1, 2, . . ., 5, to be housed (Operation 5.3)

N'''_q = the total number of students to be housed

$\overline{N}_T$ = the total number of non-resident students enrolled at the institution

F_T = the total number of professional faculty at the instiution (from Operation 4.1)

N_R = the total number of research staff at the institution (from Operation 4.4)

n_g = the number of administrative personnel in each group g, g = 1, 2, . . ., 8 (from Operation 3.3)

N_G = the total number of administrative personnel in all eight groups

n''_s = the number of instruction connected secretaries for professional faculty by rank and for graduate teaching assistants and the number of research connected secretaries, by departments (divisions) s = 1, 2, . . ., 2d (from Operation 3.5)

$\underset{1x2d}{[N_s]}$ = the row vector with components n''_s, s = 1, 2, . . ., 2d (from Operation 3.5)

N'_S = the total number of instruction and research connected secretaries

N_W = the number of library staff to be provided with work facilities (from Operation 4.40)

n'_s = the total number of all types of service employees (new input)

$\underset{1x8}{[N']}$ = the row vector with components $\overline{N}_T$, N''_q, F_T, N_R, N_G, N'_S, N_W, and n'_s

p'''_m = the percentage of the components of $\underset{1x8}{[N]}$ in the order of these components, to take meals in dining facilities at the meal with maximum number of diners, m = 1, 2, . . ., 8

$\underset{8x1}{[P'''_M]}$ = the column vector with components p'''_m, m 1, 2, . . ., 8

$[n_D]$ = the maximum number for whom dining facilities are to be provided

1x1

Note: the p'''_m must reflect the institution's decision requiring students in certain living facilities to take their meals in the dining facilities.

Models for Sub-Model 6

Operation 6.1 - Total Number of Students to be Housed

$$N'''_q = \sum_{q=1}^{5} n'_q$$

Operation 6.2 - Total Number of Non-Resident Students

$$\overline{N}_T = N_T - N'''_q$$

Operation 6.3 - Total Number of Administrative Personnel

$$N_G = \sum_{g=1}^{8} n_g$$

Operation 6.4 - Total Number of Instructional and Research Connected Secretaries

$$N'_s = \sum_{s=1}^{2d} n''_s$$

Operations 6.5 and 6.6 - Maximum Number to be Provided with Dining Facilities

$$\underset{1x8}{[N']} = \underset{1x8}{[\overline{N}_T \; N''_q \; F_T \; N_R \; N_G \; N'_s \; N_w \; n'_s]}$$

$$\underset{8x1}{[P'''_m]} = \underset{8x1}{[p'''_1 \; p'''_2 \; p'''_3 \; . \; . \; . \; p'''_8]^T}$$

$$\underset{1x1}{[n_D]} = \underset{1x8}{[N']} \times \underset{8x1}{[P'''_m]}$$

Submodel 7 - Parking Facilities

Parking facilities are considered in two groups, (1) facilities on or near campus and (2) facilities near living and dining facilities, to provide for situations in which the living and dining facilities are at some distance from the main campus. Consequently, two problems are presented for solution, (1) given a student enrollment by degree program and academic level, a faculty and research staff, an administrative staff, a secretarial and library staff, and other employees and visitors, to determine the number of automobile and other parking units required on or near campus and (2) given a student population residing in the institution's living facilities, the administrative staff for living and dining facilities, and other employees and visitors, to determine the number of automobile and other parking units required near living and dining facilities.

These problems are solved by using certain decision parameters applied to appropriate numbers of persons as inputs to the operations involved.

This part of the report gives a word description of the operations and the decision parameters used in the solution of the problems. This description is followed by a mathematical model of the solutions and a diagram illustrating the sequence of operations and decision parameters used to effect the solution.

Assumptions

1. Parking facilities are needed on or near campus and also near living and dining facilities.
2. All commuting students are to be provided with parking facilities on or near campus for attending classes.
3. Institution policies exist concerning the possession of automobiles by students, on ranks of faculty and titles of research and administrative staff to be provided with parking facilities, and on other personnel to be provided with parking facilities.
4. Department (division) chairmen and project directors in the research staff are to be provided with parking facilities.
5. Administrative personnel in groups (1-3), 6, as listed in sub-model 3, are to be provided with parking facilities.
6. A transportation study has been made to determine whether bus transportation is needed to transport students to class and, if so, the number of buses required.
7. Parking facilities are needed on or near campus and near near living and dining facilities for motorcycles, motor scooters, and bicycles.
8. Parking facilities for visitors are needed on or near campus and near living and dining facilities.
9. Public attending lectures and/or conferences can park in visitors' facilities or in student and other parking facilities not in use.
10. Parking facilities for large scale events, such as athletic contests, will be provided in planning the facilities for such events.
11. It may be desired to assign parking units for faculty by rank.
12. The department (division) chairman has the rank of professor, as in Operation 3.1.

A. Parking Facilities On Or Near Campus - Operations 7.1 - 7.12

Operation 7.1 - Number of Non-Commuting Students Allowed to Have Automobiles

Input

The input to Operation 7.1 is the output from Operation 5.6, the total number of non-commuting students.

Decision Parameter

The decision parameter for this operation is the percentage of the total number of non-commuting students who are allowed to have automobiles.

The Operation

This operation consists of multiplying the input by the decision parameter.

Output

The output from Operation 7.1 is the total number of non-commuting students who are allowed to have automobiles.

Operation 7.2 - Formation of Row Vector for Operation 7.3

Input

The inputs to Operation 7.2 are the outputs from Operation 7.1, the total number of non-commuting students who are allowed to have automobiles, and the total number of commuting students, as used in Operation 5.1.

The Operation

This operation merely arranges the inputs for the performance of the next operation.

Output

The output from Operation 7.2 is the arrangement of the inputs for Operation 7.3.

Operation 7.3 - Total Number of Student Parking Units On Or Near Campus

Input

The input to Operation 7.3 is the output from Operation 7.2.

Decision Parameter

The decision parameter for this operation is the percentage of non-commuting students allowed to have automobiles who are to be provided with parking facilities on or near campus.

The Operation

This operation consists of multiplying the total number of non-commuting students allowed to have automobiles by the decision parameter and adding to this product the total number of commuting students.

Output

The output from Operation 7.3 is the total number of student parking units on or near campus.

Operation 7.4 - Formation of Matrices for Operation 7.5

Input

The inputs to Operation 7.4 are the number of department (division) chairmen; the number of project directors in the research staff assigned to each department (division); the number of professors, excluding the chairman, in each department (division); the number of associate professors, the number of assistant professors, the number of instructors, in each department (division); and the number of research staff, excluding project directors, assigned to each department (division).

The Operation

This operation arranges the inputs in a form suitable for the next operation.

Output

The output from Operation 7.4 is the arrangement of the inputs for performing Operation 7.5.

Operation 7.5 - Total Number of Professional Faculty and Research Staff Parking Units On Or Near Campus

Input

The inputs to Operation 7.5 are the inputs to Operation 7.4 as arranged by Operation 7.4.

Decision Parameters

The decision parameters for this operation are the percentages of the inputs to be provided with parking facilities, the department (division) chairmen and research staff project directors each being allotted parking facilities.

The Operation

Operation 7.5 consists of summing a.) the number of department (division) chairmen, b.) the number of research staff project directors and c.) the products obtained by multiplying the number of professors (excluding department chairmen), the number of associate professors, the number of assistant professors, the number of instructors, and the number of research staff (excluding project directors) by the appropriate decision parameter.

Output

The outputs from Operation 7.5 are the number of parking units, on or near campus, for department (division) chairmen, research staff project directors, professors, associate professors, assistant professors, instructors and research staff other than project directors.

Operation 7.6 - Formation of Row Vector for Operation 7.7

Input

The inputs to Operation 7.6 are the number of administrative personnel in groups (1-5), as in Operation 3.3.

The Operation

This operation arranges the inputs for the performance of the next operation.

Output

The output from Operation 7.6 is an arrangement of the inputs for use in Operation 7.7

Operation 7.7 - Total Number of Administration Personnel Parking Units On Or Near Campus

Input

The input to Operation 7.7 is the output from Operation 7.6, the number of administrative personnel in groups (1-5) as there arranged.

Decision Parameters

The decision parameters for this operation are the percentages of the number in each of the administrative groups (1-5) to be provided with parking facilities on or near campus, with the parameter for those in groups (1-3) being 1.

The Operation

This operation consists of multiplying the number of persons in each group (1-5) by the appropriate decision parameter and adding the products so formed.

Output

The output from Operation 7.7 is the number of administrative personnel parking units on or near campus.

Operation 7.8 - Formation of Row Vector for Operation 7.9

Input

The inputs to Operation 7.8 are the outputs from Operations 6.4, and 4.40, i.e., the number of instruction and research connected secretaries and the number of the library staff provided with work facilities; and the total number of all types of service employees, as in Operation 6.5.

The Operation

This operation arranges the inputs suitably for the next operation.

Output

The output from Operation 7.8 is an arrangement of the inputs for use in Operation 7.9.

Operation 7.9 - Total Number of Instruction and Research Connected Secretaries', Library Staff, Workers' and Service Employees' Parking Units On or Near Campus

Input

The input to Operation 7.9 is the output from Operation 7.8, the arrangement of the inputs to Operation 7.8.

Decision Parameters

The decision parameters for this operation are the percentages of the inputs to be provided with parking facilities on or near campus.

The Operation

This operation consists of multiplying each of the inputs by the proper decision parameter.

Output

The outputs from Operation 7.9 are the number of instruction and research connected secretaries' parking units; the number of library staff, provided with work facilities, parking units; the number of service employees' parking units; all on or near campus.

Operation 7.10 - Total Number of Automobile Parking Units On Or Near Campus

Input

The inputs to Operation 7.10 are the outputs from Operation 7.3, 7.5, 7.7, 7.9, and the number of visitors' parking units on or near campus.

The Operation

Operation 7.10 consists of adding the several inputs to the operation.

Output

The output from Operation 7.10 is the total number of automobile parking units on or near campus.

Operation 7.11 - Number of Parking Units On Or Near Campus for Students' Motorcycles, Motor Scooters, and Bicycles

P_M

Operation 7.12 - Number of Bus Parking Units On Or Near Campus

P_B

B. Parking Facilities Near Living and Dining Facilities - Operations 7.13 - 7.20

Operation 7.13 - Total Number of Resident Students Allowed to Have Automobiles

Input

The inputs to Operation 7.13 are the output from Operation 6.1, the total number of students to reside in living facilities, and a new input, the total number of students to reside in living facilities but not permitted to have automobiles.

The Operation

Operation 7.13 consists of subtracting the number of students residing in living facilities but not permitted to have automobiles from the total number of students residing in living facilities.

Output

The output from Operation 7.13 is the total number of students to reside in living facilities and permitted to have automobiles.

Operation 7.14 - Number of Resident Students' Parking Units Near Living and Dining Facilities

Input

The input to Operation 7.14 is the output from Operation 7.13, the total number of students to reside in living facilities and permitted to have automobiles.

Decision Parameter

The decision parameter for this operation is the percentage of the number of students to reside in living facilities and permitted to have automobiles who are to be provided with parking facilities near living and dining facilities.

Output

The output from Operation 7.14 is the total number of student parking units near living and dining facilities.

Operation 7.15 - Formation of Row Vector for Operation 7.16

Input

The inputs to Operation 7.15 are the numbers of administrative personnel in groups (6-8), from Operation 3.3.

The Operation

This operation merely arranges the inputs suitably for the next operation.

Output

The outputs from Operation 7.15 are the inputs to this operation, arranged for Operation 7.16.

Operation 7.16 - Number of Administrative Parking Units Near Living and Dining Facilities

Input

The input to Operation 7.16 is the output from Operation 7.15.

Decision Parameters

The decision parameters for this operation are the percentages of each of the inputs to be provided with parking facilities near living and dining facilities, the persons in group 6 each being allotted parking facilities.

The Operation

Operation 7.16 adds to the number of persons in group 6 the products of each of the other two inputs multiplied by the appropriate decision parameter.

Output

The output from Operation 7.16 is the total number of administrative parking units near living and dining facilities.

Operation 7.17 - Number of Service Employees' Parking Units Near Living and Dining Facilities

Input

The input to Operation 7.17 is the total number of all types of service employees, as in Operation 6.5.

Decision Parameter

The decision parameter for this operation is the percentage of the total number of all types of service employees to be provided with parking facilities near living and dining facilities.

The Operation

Operation 7.17 consists of multiplying the input, the total number of all types of service employees, by the decision parameter.

Output

The output from Operation 7.17 is the total number of service employees' parking units near living and dining facilities.

Operation 7.18 - Total Number of Automobile Parking Units Near Living and Dining Facilities

Input

The inputs to Operation 7.18 are the outputs from Operations 7.14, 7.16, 7.17, i.e., the total number of student parking units, the total number of administrative parking units, and the total number of service employees' parking units, together with a new input, the total number of visitors' parking units, all near living and dining facilities.

The Operation

This operation consists of adding the inputs.

Output

The output from Operation 7.18 is the total number of automobile parking units near living and dining facilities.

Operation 7.19 - Motorcycle, Motor Scooter and Bicycle Parking Units Near Living and Dining Facilities

P'_M

Operation 7.20 - Number of Bus Parking Units Near Living and Dining Facilities

P'_B

Symbols

A. Parking Facilities On Or Near Campus

N'_T = the total number of non-commuting students (from Operation 5.1) = $\sum_{q=1}^{5} N''_q$

n'_c = the total number of commuting students (as in Operation 5.1) = $N_T - N'_T$

r' = the percentage of N'_T allowed to have automobiles

N_A = the number of non-commuting students allowed to have automobiles

r'_2 = the percentage of N_A to be provided with parking facilities on or near campus

P_S = the total number of student parking units on or near campus

f_{i6} = the number of persons in the research staff, excluding project directors, assigned to department (division) i, i = 1, 2, . . ., d (as in Operation 4.3)

$\underset{1x7d}{[F''']}$ = the row vector formed from [F], in Operation 3.1, and f_{i6} as specified in the following model

r'_3 = the percentage of the number of professors to be provided with parking facilities

r'_4 = the percentage of the number of associate professors to be provided with parking facilities

r'_5 = the percentage of the number of assistant professors to be provided with parking facilities

r'_6 = the percentage of the number of instructors to be provided with parking facilities

r'_7 = the percentage of the number of research staff, excluding project directors, to be provided with parking facilities

$\underset{7dx7}{[R_1]}$ = the matrix with elements 1, r'_3, r'_4, . . ., r'_7, as shown below

P_f = for f = 1, 2, . . ., 7, the total number of parking units for department (division) chairmen, research project directors, professors, associate professors, assistant professors, instructors, and other research staff in this order.

$\underset{1x7}{[P_F]}$ the row vector with components P_f, $f = 1,2, . . ., 7$

n'_g = the total number of administrative personnel in group g, $g = 1, 2, . . ., 5$, (from Operation 3.3)

r'''_6 = the percentage of n_4, the administrative personnel requiring only office facilities, to be provided with parking facilities on or near campus

r'''_7 = the percentage of n_5, the secretaries to administrative personnel in groups (1-4) plus secretaries in the secretarial pool, to be provided with parking facilities on or near campus

$\underset{1x5}{[N'_G]}$ = the row vector with components $n_1, n_2, . . ., n_5$

$\underset{5x1}{[R_2]}$ = the column vector with components 1, 1, 1, r'''_6, r'''_7

$\underset{1x1}{[P_A]}$ = the total number of administrative personnel parking units on or near campus

N'_s = the total number of instruction and research connected secretaries (from Operation 6.4)

r''_1 the percentage of N'_s to be provided with parking facilities on or near campus

P_s = the total number of instruction and research connected secretaries' parking units on or near campus

N_w = the number of library staff to be provided with work facilities (from Operation 4.40)

r''_2 = the percentage of N_w to be provided with parking facilities on or near campus

P_L = the total number of library staff, provided with work facilities, parking units on or near campus

n'_s = the total number of all types of service employees (as in Operation 6.5)

r''_3 = the percentage of n'_s to be provided with parking facilities on or near campus

P_e = the total number of service employees' parking units on or near campus

P_v = the total number of visitors' parking units on or near campus

P_T = the total number of automobile parking units on or near campus

P_M = the number of parking units on or near campus for students' motorcycles, motor scooters, and bicycles.

P_B = the number of bus parking units on or near campus

B. Parking Facilities Near Living and Dining Facilities

N'''_q = the total number of students to reside in living facilities (from Operation 6.1)

n_w = the total number of students to reside in living facilities but not permitted to have automobiles (new input)

N^{iv}_q = the total number of students to reside in living facilities and permitted to have automobiles

r_p = the percentage of N'''_q to be provided with parking facilities near living and dining facilities

P'_S = the total number of student parking units near living and dining facilities

n''_g = the number of administrative personnel in each group g, g = 6, 7, 8 (Operation 3.3)

$\underset{1\times3}{[N''_G]}$ = the row vector with components n_6, n_7, n_8

r''_4 = the percentage of n_7 to be provided with parking facilities near living and dining facilities

r''_5 = the percentage of n_8 to be provided with parking facilities near living and dining facilities

$\underset{3\times1}{[R_3]}$ = the column vector with components 1, r''_4, r''_5

$\underset{1\times1}{[P'_A]}$ = the total number of administrative parking units near living and dining facilities

n'_s = the total number of all types of service employees (as in Operation 6.5)

r''_6 = the percentage of n'_s to be furnished with parking facilities near living and dining facilities

P'_e = the total number of service employees' parking units near living and dining facilities

P'_v = the total number of visitors' parking units near living and dining facilities (new input)

P'_T = the total number of automobile parking units near living and dining facilities

P'_M = the number of parking units near living and dining facilities for students' motorcycles, motor scooters, and bicycles

P'_B = the number of bus parking units near living and dining facilities

The Models

A. Parking Facilities On Or Near Campus

Operation 7.1 - Number of Non-Commuting Students Allowed to Have Automobiles

$$N_A = N_T' \times r_1'$$

Operations 7.2 and 7.3 - Total Number of Student Parking Units On Or Near Campus

$$\underset{1\text{x}1}{[P_S]} = \underset{1\text{x}2}{[N_A \; n_c']} \times \underset{2\text{x}1}{[r_2' \; 1]^T}$$

Operations 7.4 and 7.5 - Total Number of Professional Faculty and Research Staff Parking Units On Or Near Campus

$$\underset{1\text{x}7d}{[F''']} = \underset{1\text{x}7d}{[\overbrace{1 \; 1 \; . \; . \; . \; 1}^{d} \; f_{15} \; f_{25} \; . \; . \; . \; f_{d5} \;\; (f_{11}-1) \; (f_{21}-1) \; . \; . \; . \; (f_{d1}-1)}$$

$$f_{12} \; f_{22} \; . \; . \; . \; f_{d2} \; . \; . \; . \; f_{d4} \; . \; . \; . \; f_{16} \; f_{26} \; . \; . \; . \; f_{d6}]$$

$$\underset{7dx7}{[R_1]} = \underset{7dx7}{\begin{bmatrix}
1 & 0 & 0 & . & 0 \\
1 & 0 & 0 & . & 0 \\
. & . & . & . & . \\
. & . & . & . & . \\
. & . & . & . & . \\
1 & 0 & 0 & . & 0 \\
0 & 1 & 0 & . & 0 \\
0 & 1 & 0 & . & 0 \\
. & . & . & . & . \\
. & . & . & . & . \\
0 & 1 & 0 & . & 0 \\
0 & 0 & r'_3 & . & 0 \\
0 & 0 & r'_3 & . & 0 \\
. & . & . & . & . \\
. & . & . & . & .. \\
. & . & . & . & . \\
0 & 0 & r'_3 & . & 0 \\
0 & 0 & 0 & . & 0 \\
. & . & . & . & . \\
0 & 0 & 0 & . & r'_7 \\
0 & 0 & 0 & . & r'_7 \\
. & . & . & & . \\
. & . & . & & . \\
. & . & . & & . \\
0 & 0 & 0 & . & r'_7
\end{bmatrix}}$$

$$\underset{1x7}{[P_F]} = \underset{1x7}{[P_1\ P_2\ .\ .\ .\ P_7]} = \underset{1x7d}{[F''']} \text{ x } \underset{7dx7}{[R_1]}$$

Operations 7.6 and 7.7 - Total Number of Administrative Personnel Parking Units On Or Near Campus

$$\underset{1x5}{[N'_G]} = [n_1\ n_2\ n_3\ n_4\ n_5]$$

$$\underset{5x1}{[R_2]} = \underset{5x1}{[1\ 1\ 1\ r'''_6\ r'''_7]^T}$$

$$\underset{1x1}{[P_A]} = \underset{1x5}{[N'_G]} \text{ x } \underset{5x1}{[R_2]}$$

Operations 7.8 and 7.9 - Total Number of Instruction and Research Connected Secretaries', Library Staff Workers', and Service Employees' Parking Units On Or Near Campus

$$\underset{1x3}{[P_s\ P_L\ P_e]} = \underset{1x3}{[N'_s\ N_w\ n'_s]} \text{ x diag } \underset{3x3}{[r''_1\ r''_2\ r''_3]}$$

Operation 7.10 - Total Number of Automobile Parking Units On Or Near Campus

$$P_T = P_S + \left(P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7\right) + P_A + \left(P_s + P_L + P_e\right) + P_v$$

Operation 7.11 - Motorcycle, Motor Scooter and Bicycle Parking Units On Or Near Campus

$$P_M$$

Operation 7.12 - Bus Parking Units On Or Near Campus

$$P_B$$

B. Parking Facilities Near Living and Dining Facilities

Operation 7.13 - Number of Resident Students Allowed to have Automobiles

$$N_q^{iv} = N_q''' - n_w$$

Operation 7.14 - Number of Resident Students' Parking Units Near Living and Dining Facilities

$$P_S' = N_q^{iv} \times r_p$$

Operation 7.15 and 7.16 - Number of Administrative Parking Units Near Living and Dining Facilities

$$\underset{1x3}{[N_G'']} = \underset{1x3}{[n_6\ n_7\ n_8]}$$

$$\underset{3x1}{[R_3]} = \underset{3x1}{[1\ r_4''\ r_5'']^T}$$

$$\underset{1x1}{[P_A']} = \underset{1x3}{[N_G'']} \times \underset{3x1}{[R_3]}$$

Operation 7.17 - Number of Service Employees; Parking Units Near Living and Dining Facilities

$$P_e' = n_s' \times r_6''$$

Operation 7.18 - Total Number of Automobile Parking Units Near Living and Dining Facilities

$$P_T' = P_S' + P_A' + P_e'\ P_v'$$

Operation 7.19 - Motorcycle, Motor Scooter and Bicycle Parking Units Near Living and Dining Facilities

$$P_M'$$

Operation 7.20 - Bus Parking Units Near Living and Dining Facilities

$$P_B'$$

Conclusion

This report demonstrates one way in which the fundamental variables affecting requirements for certain types of physical facilities can be linked mathematically to form models of the facilities needs of institutions of higher learning. Application of the techniques of submodel 1 to historical data associated with a variety of Rensselaer's academic departments has indicated that this particular submodel is capable of satisfactorily reproducing past situations. This is the only one of the submodels which has been tested with any degree of thoroughness. Inasmuch as the other submodels are relatively less complex, their applicibility is determined much more by data availability than by the validity of the structural aspects of the models.

In the process of constructing these models, a good deal was learned about the nature of the constraints on the model-building process. First, it soon became evident that there are serious limitations as to the types of facilities which can profitably be included in such a model. In particular, the types of space which are only indirectly related to the demands generated by the major input to the system, i.e., the student, are extremely difficult to model in any meaningful way. Reference is made specifically to administrative space, and to a lesser extent, to research space.

The model-building process also made obvious the extreme importance of the decision parameters. The models which have been developed highlight the fact that it is the controllable factors regarding how things are done which are of maximum consequence. The input data requirements are relatively small in comparison to the types and amounts of information required by the decision parameters. In fact, recognition of the role of the decision element in the modeling process may well be the most important contribution of this study.

In general, the construction of the submodels has been found to be a comparatively trivial problem; it is the general absence of the information required to form the bases for quantifying the decision parameters which is the major problem to be faced when developing an institutional model.

It should be noted that models such as those presented in this report find their greatest usefulness because of the problems associated with quantification of the decision parameters. In view of these difficulties, the ability to investigate the results of using a variety of values for certain of the parameters becomes necessary. The adaptability of such models to simulation techniques is probably their single greatest advantage.

The technique for translating the outputs of the submodels to square feet which is explained in the appendix is a logical extension of the basic report. The technique represents a novel approach to this particular problem and carries out the philosophy that the user and his requirements determine space needs, the philosophy which has been maintained throughout this report.

It is recognized that nothing contained herein is a final answer to the problems associated with modeling educational facilities needs. In fact, further development of these models is presently in progress. If this work serves as a valid point of departure for further development of such models, this project will have been an extremely useful exercise.

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APPENDIX A

AN APPROACH TO PROJECTING AREA REQUIREMENTS FOR COLLEGE AND UNIVERSITY OFFICE ACTIVITIES

an appendix to

AN EXPLORATORY STUDY OF THE PHYSICAL FACILITIES REQUIREMENTS
OF INSTITUTIONS OF HIGHER LEARNING

a study conducted by Rensselaer Polytechnic Institute for the
Office of Economic and Manpower Studies, National Science Foundation

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Center for Architectural Research, Rensselaer Polytechnic Institute, September 1968

INTRODUCTION

the purpose of this appendix

The foregoing presents a model which can be used to project university facility needs. By adding information about his own situation and by writing many of his own "rules", the individual user can translate this situation into space needs. Through repeated iterations, he can simulate the effect of changing conditions on his requirements for space.

The common denominator of campus space is square footage: the ultimate objective of the model is to translate people and curricula into square foot requirements; using current cost formulas, the user will then be able to make the move from area to cost.

The outline model presented in the main body of this report manipulates students, programs, instructional approaches, departmental profiles, and other factors into the stations required for various activities -- the number and type of instructional stations, faculty office stations, housing stations, and so forth. What is required next is to translate these "units of space demand" into space itself.

This translation is not an easy one. There are many existing approaches, and most of them suffer from flaws of one kind or another. The purpose of this appendix is to develop and illustrate a rational technique for making this translation from "stations" to "square feet".

the contribution

It is important to clearly state the thrust of this appendix. It will be shown that existing approaches to "planning factors" are subject to question. Based on our mistakes to date, an improved approach to making the translation will be investigated. One submodel proposed in the text of the report will then be carefully examined as a case study.

It is at this point that the appendix must stop. Limited resources suggest that the greatest contribution lies in a pilot effort of some depth, rather than an all-inclusive approach which simply averages some of the currently-used planning standards. It is hoped that enough material -- both theory and application -- is presented to lay the groundwork for an effort which would appropriately derive all the necessary planning approaches and space factors.

using the model: two "modes"

Before any attempt is made to begin the translation from "stations" to "square feet", it is important to briefly analyze how a university may use the proposed model. While it is possible to apply many labels, it is suggested that the model may be used in two general "modes":

- THE LONG-RANGE BUDGETING MODE, where it is desirable to translate the given inputs into very large "pools" of space. In long-range planning, we may be interested in determining the overall size of a campus or of its academic/administrative entities (schools, colleges, offices, departments, etc.). We may wish to further divide this space by broad functional categories: instructional, office, research, etc. We are not interested, however, in buildings unless they conform directly to academic/administrative or functional categories (i.e., a "chemistry building" or a "research building"), and we are certainly not interested in individual rooms at this point.

- THE SHORT-RANGE PLANNING MODE, where it is necessary to take a closer look at space and to allocate it to the institution's academic/administrative entities and to the specific people or activities within those entities.

Of course, there is no firm point at which a user crosses from one mode to the other; sometimes he may be operating within both at once. There are, however, differences which will become significant. The user will demand more accurate and more refined data in the short-range mode; correspondingly he will be able to answer the detailed questions required to get this information. In short, the model's appearance to the user will change as he moves from long- to short-range planning.

making the translation: two issues

No matter which mode the user may be in at any moment, his use of the model to translate "stations" into "square feet" will involve two heavily interrelated issues:

- A DECISION PATH; or a series of questions which he must answer. As the questions are asked and answered, the model will be able to zero in on an appropriate,
- AREA STATEMENT which will actually complete the translation.

Again this dichotomy is more than academic. It will be shown that there are no single "factors" translating activities and philosophies into statements about area required. An area statement becomes valid only after the user has traversed a maze which explicitly leads to that factor. As will be seen, the maze may be simple and straight-line, or it may be complex and loaded with turns and switchbacks. In any case, area statements are suggested only after user and system commonly decide what is needed to do the job.

These issues cannot be easily separated. The determination of the area statements will depend on the process used to create them in the first place, and conversely, the questions asked each university must be relevant in terms of the factors to be applied: why ask a question if the answer makes no difference in terms of square footage?

the decision path

The decision path (or questions to be answered by the individual user) depends entirely on the general space type under consideration. A decision path for one of the proposed submodels will be developed later in this appendix. As suggested above, the decision path can be developed only with an acute awareness of,

- what decisions are relevant in terms of influencing space needs, and,
- in what order decisions should be made.

the area statement

While the development of the decision path depends on an awareness of human activities and educational and administrative policy in manipulating these activities, the derivation of a translating statement assumes that (1) these activities and policies do influence space needs, and that (2) this "influence" can be measured in terms of square feet.

These determinations are not easy. First, there is not even an accepted methodology for making them. Looking at the model already presented, for example, one can see that in making the initial calculations for the number of office or instructional stations required, traditional "rules" can be followed; master schedules can be examined, departmental profiles can be created, and so forth. There is little there which is not within the realm of accepted practice; the challenge is in doing the job simply and effectively. Questions revolve around ease of use, simplicity of input, and development of simulation techniques. In no case is the actual methodology a problem.

Such is not the case when making the translation from the number of stations involved to the area required by these stations.

One approach is, of course, to create a simple "factor" which is used as a multiplier: "a lecture hall should be planned on the basis of 13.6 (or whatever) square feet per station". The temptation in working with a model such as the one presented here is to simply "apply" this factor (often called a planning standard). There are many of these planning standards in force, and recent experience has often dramatized their inadequacies. An analysis of many educational buildings will quickly reveal that what is really happening rarely coincides with what was planned to happen. Lecture halls carefully programmed for 120 students wind up with 98 seats; 2 laboratories, both programmed for 20 stations and both of the same area, house 17 and 24 stations respectively; faculty offices of the "appropriate" size turn out to be too small; there are dozens of other misfits in most of our university buildings.

Why? Why do planning standards often produce these misfits? There are a number of reasons, all of which should be carefully examined in order to put the translation process into perspective:

1. What actually happens in spaces may not be reflected in their labels.

2. What actually happens in spaces may not be reflected in their planning standards. Too often the standards are developed on someone's ideal rather than on a careful analysis of human ac-

tivity in space.

3. Area requirements do not assure efficiency of layout. Identical floor areas may not be equally usable due to differences in ciruulation or because of variations of furniture and equipment layout, location of doors and windows, protrusions into the room, etc.

4. While planning standards are carefully derived for the parts of the building, there may be no real relation to the whole. Too often space conserved within rooms is used up in corridor area getting to the rooms. Our preoccupation with "net" areas often ignores the fact that the "net-to-gross" conversion ends up wasting space.

5. Area requirements are not strictly products of the two-dimensional space required for human activity. The quality of the environment, physical and visual access to other spaces and to the outdoors, height, and several other factors all color our reaction to the amount of space needed.

6. Planning standards often reflect influences which are not strictly functional in nature. Offices, for instance, are often sized by the position or rank of the occupant rather than his actual area needs.

7. Existing planning standards may not take new educational philosophies and human activity patterns into account. Hence many plan-

ning standards are mistakenly applied in building programming.

If these flaws in current planning standards are so obvious, one can reasonably ask why they haven't been improved.

First, only recently has the architectural profession become interested in the study of human activities and human environmental needs. Consequently there are no "accepted practices" or methodologies in this field.

Secondly, the measurement of human needs and their implications for physical environment assumes a link between activity and environment. While we all suspect that this link exists ("We shape our buildings, and thereafter they shape us"), it has not been proven in any measurable terms. This "proof" necessarily requires co-operation among architects, psychologists, sociologists, and others concerned with human behavior and activity. These multi-lateral ventures have only just begun.

Because there is no real measurement methodology and because there are so many factors involved in developing space planning criteria, past approaches fall squarely in the survey-and-consensus category. Existing space use is surveyed in statistical terms, and the statistics are then massaged into planning standards. There is (or can easily be) no real analysis of human activity in space and human reaction to space. After we have built many buildings with our planning standards, we usually compound our original errors by including the new spaces in our new survey-and-consensus. In this way untested assumptions become standards through repeated use, and new surveys merely confirm their acceptance.

A CASE STUDY: OFFICES

the need to limit the study

The foregoing report presents the outline of a facilities projection system in five major areas: instructional space, office space, research space, library space, and housing and dining space.

A full translation of each of these "submodels" into square footage planning factors is impossible. As has been suggested, there is little accepted methodology for determining space factors, and methodology has to be derived-as-you-go. With a few short weeks and a limited budget, it was felt that a deep penetration into one area, rather than a shallow assault on all areas, would best serve the ends of the study.

One submodel -- office facilities -- has been selected for further study. It is hoped that this exploration in depth will not only provide some valid answers, but that it will also point out weaknesses in traditional approaches to space planning factors. Perhaps it can serve as a prototype for the kind of studies which would have to be launched for the other submodels.

why offices?

The selection of the office submodel for this case study was not made spuriously. There were several contributing factors;

1. Compared to many university facilities, the office is relatively "uncomplex" (note the use of this word in the place of "simple"). This is important where

time is short and resources limited.

2. Its very "uncomplexity" has allowed many interested in facilities planning to consider it trivial. Hence the college office is relatively unstudied. This allows room for fresh thinking.

3. The office is well within the realm of the investigators' experience. This precludes the need for long and detailed familiarization.

4. Traditional space planning standards for offices do not adequately reflect the patterns of human activity within them. Most square footages are derived from survey-and-consensus approaches; these simply perpetuate the existing rank-sized office scheme*.

5. The office submodel in the system proposed in this report is relatively well-developed. It is in a form which easily allows the addition of the "decision-path" in order to make the translation to facilities.

Each of these points is significant. The unique combination of these factors noted here was not available when the other four submodels were examined for in-depth study. Either they were too complicated, too fraught with subtleties and nuances for what must amount to brief study, too well studied (with invalid approaches and misleading results), or the model was simply not yet in a form which allows smooth translation into space factors. The office seems to, above all, pose the prospect of a fresh new look without undue reliance on traditional survey-and-consensus attempts.

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*This is not to suggest the rank-sizing of offices is invalid; indeed an individual college may wish to do it this way. If it does not, however, the appropriate planning factors do not exist.

approaching the case study

The case study will be limited to "offices" -- that is, the "office" needs of professional faculty, adjunct faculty, research staff*, administrative and clerical personnel. There are times when some of these occupants will be singled out for emphasis, but the activity analysis, the decision paths, and resulting space factors will be designed to accommodate them all.

what is an office?

When asked this question, most people conjure up images of walls and desks and chairs and files -- the physical artifacts which do indeed comprise an office. More important than any of these things, however, are the activities which are undertaken there. Offices are places -- not places for desks and shelves, but places for working, reading, meeting with people, research, accounting, and the hundreds of other activities which when summed are the university.

What an office "is", then, is a product of the activities it houses. For this reason, any effort to convert stations and people to square feet must necessarily be built around their activities. It is with these activities that we shall begin the presentation of the case study.

the range of activities

The range of activities that members of the faculty, staff, and administration undertake in offices and office-related spaces is indeed a very broad one. For purposes of illustration, an imaginary professor has been created, and a diary of his activities is presented as Figure A1. From the diary, several points can be noted,

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*Research laboratories are considered separately (in submodel 2) and thus are not part of this appendix.

1. Professor X does indeed undertake a wide variety of activities.
2. All of these activities require physical accommodation of some sort.
3. Many of these activities take place in offices, but many others take place in office-related spaces.
4. Any model attempting to project space needs will have to accommodate both office and office-related activities.

This last point is particularly pertinent. The office submodel will inevitably deal with activities which are office-related as well as strictly office-housed. Some activities may be in either category; a small-group conference activity, for instance, may take place within an office or within a conference room. The ultimate square footage required will indeed depend on where it takes place, the kinds of privacy needed, the ability to share space with others engaging in similar functions, and a number of other factors. The model should recognize these influences.

listing activities

Using this activity-oriented approach to generating space needs, the first step is to list the kinds of activities which may be undertaken in office and office-related spaces. No matter who the occupant is, these may include,

DIARY OF PROFESSOR X

(activity)	(place)	(accommodation in model)
Park car; walk to office area	parking lot, corridors	possible future submodel; net-to-gross conversion
Inform secretary of presence	clerical office	office submodel
Shed coat and outer wrap	wardrobe	office submodel
Pick up a cup of coffee	workroom	office submodel
Meet four colleagues in a committee session	conference room	office submodel
Finish meeting; discuss issues with a colleague	hallway	too informal to include
Pick up morning mail	clerical office	office submodel
Dictate responses to mail	office (desk)	office submodel
Give dictation and instructions to secretary	clerical office	office submodel
Assemble resources and notes for class presentation	office (desk, files, shelves)	office submodel
Prepare drawing for handout	office (table)	office submodel
Duplicate materials for handout	workroom	office submodel
Meet class	classroom	instructional submodel
Discuss with students after class	hallway	too informal to include
Meet seminar group in office	office (seating area)	office submodel
Answer telephone	office (desk)	office submodel
Counsel an individual student	office (seating area)	office submodel
Eat lunch	office (desk)	office submodel
Interview a prospective faculty member	office (seating area)	office submodel
Supervise a research experiment	laboratory	research submodel
Undertake a bibliography search as part of project	office (desk, files, shelves)	office submodel
Discuss status of project with assistants	office (seating area, blackboard)	office submodel
Grade papers and tabulate	office (desk, calculator)	office submodel
Attend a departmental faculty meeting	conference room	office submodel
Relax and read	office (seating area; desk)	office submodel
Leave for the day!		

Figure A1: A "DIARY" OF A FACULTY MEMBER'S ACTIVITIES

(individual)

thinking
reading
writing
telephoning
dictating
grading
problem-solving
calculating
typing
drawing
drafting
collating, binding
filing
retrieving materials
eating
relaxing
storage of wraps

(group)

reception
counseling
interviewing
seminar
committee meeting
personal dictation
display
storage of wraps

These lists are certainly not all-inclusive; nor do they need to be. Nor furthermore, do all officeholders undertake each of these activities; the listing for a Dean would certainly differ from that of the Purchasing Agent and that of a research secretary. The important thing is to realize that space requirements come from a certain knowledge of what will be undertaken in that space, and that "office" is far from a unilateral term with one single set of facility implications.

grouping activities by their space implications

As interesting as activity lists may be, they cannot be directly translated into square footages. A telephone takes up space, for instance, but it usually sits on a larger entity called a desk, which also takes up space. Because they take up the same space, it is not accurate to simply associate a square footage with every activity and then look at an office as a summation of those figures.

This suggests a grouping of activities into "zones". These zones, if properly created, will not only take up space, but will take up a definable amount of space. The activity "zone", then, is a most useful concept -- a concept which allows the translation from office activities to required office space.

Creating these zones is not an easy task, and certainly further analysis of office activities will be needed to develop a truly useful list. A first attempt might include the following zones,

ZONE A: DESK, including thinking, reading, writing, telephoning, machine dictation, grading, desk problem-solving, calculating, typing, drawing, filing (below desk files), eating, relaxing, and other desk-oriented activities.

ZONE B: ADJUNCT WORK TABLE, including writing, reading, grading, problem-solving, calculating, typing, collating, binding, and other activities performed at an adjunct work surface.

ZONE C: SHELF STORAGE, including storage and retrieval of materials from shelving.

ZONE D: FILE STORAGE, including storage and retrieval of materials from various types of filing devices.

ZONE E: WARDROBE, including storage and retrieval of coats, wraps, etc.

ZONE F: INDIVIDUAL CONFERENCE, including reception, counseling, interviewing, personal dictation, discussion, and other one-to-one conference activities.

ZONE G: SMALL-GROUP CONFERENCE (2-4 people), including reception, discussion, and other small-group conference activities.

ZONE H: MEDIUM-GROUP CONFERENCES (4-10 people), including discussion, display, and other medium-group conference activities.

ZONE I: LARGE-GROUP CONFERENCE (10 or more people), including discussion, display, and other large-group conference activities.

In addition to these nine basic types of activity zones, it is possible to list three additional "special" activity zones,

ZONE J: SPECIAL WORK, including work areas for office activities not included in Zones A and B. This would include drafting activities, computer terminals, blackboards and associated access activities, duplicating and copying, and others. Special laboratory stations would have to be determined in conjunction with the Research Submodel.

ZONE K: SPECIAL STORAGE, including storage activities not specifically referenced in Zones C through E. This would include storage of special materials, office supplies, etc.

ZONE L: SPECIAL GROUP, including accommodations for group activities not included in Zones F through I. This would include staff lounges, special reception areas, and any other meeting areas which are office-related but not included in the instructional or research submodels.

sizing these zones

In order to size these zones, it is quite clear that each will have to be individually examined. It is also clear that the approaches to sizing will have to differ between the first nine "basic" activity zones and the last three "special" activity zones. Figure A2 will serve to clarify just what each of these zones is, and how each might translate into square feet.

For each of the twelve proposed activity zones, a number of "example alternatives" have been provided. There is no clue to their accuracy, and certainly these figures cannot be taken for granted. The following methodology is proposed for determining

ZONE A: DESK

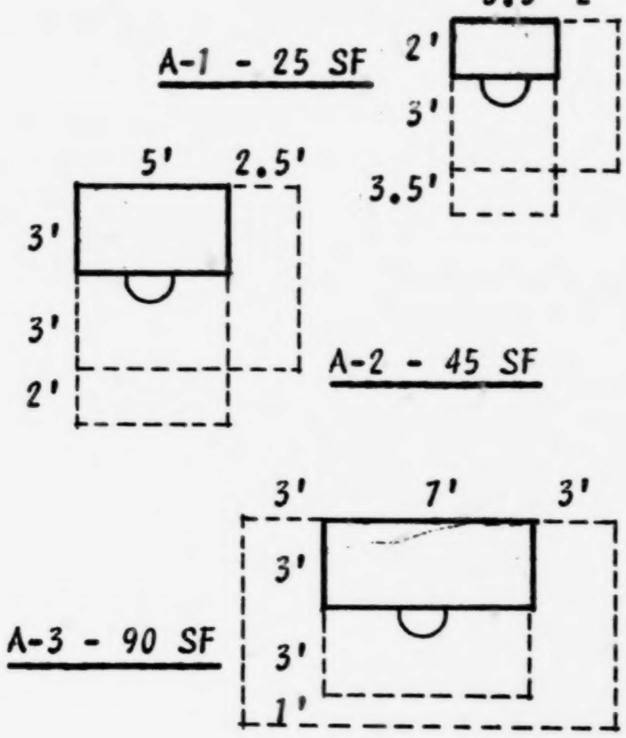
activities: thinking, reading, writing, telephoning, machine dictation, grading, problem-solving, calculating, typing, drawing, under-desk filing, eating, relaxing, etc.

size variables: position of occupant; amount of breathing space around the desk.

dedication: usually not shared.

compatibility: may or may not be combined with other activity zones.

example alternatives: 3 are shown.



ZONE B: ADJUNCT WORK TABLE

activities: writing, reading, grading, problem-solving, calculating, typing, collating, binding, etc.

size variables: what it is used for and how important adjunct work space is to the office holder; combination with other zones.

dedication: usually not shared.

compatibility: may or may not be combined with other activity zones.

example alternatives: 3 are shown.

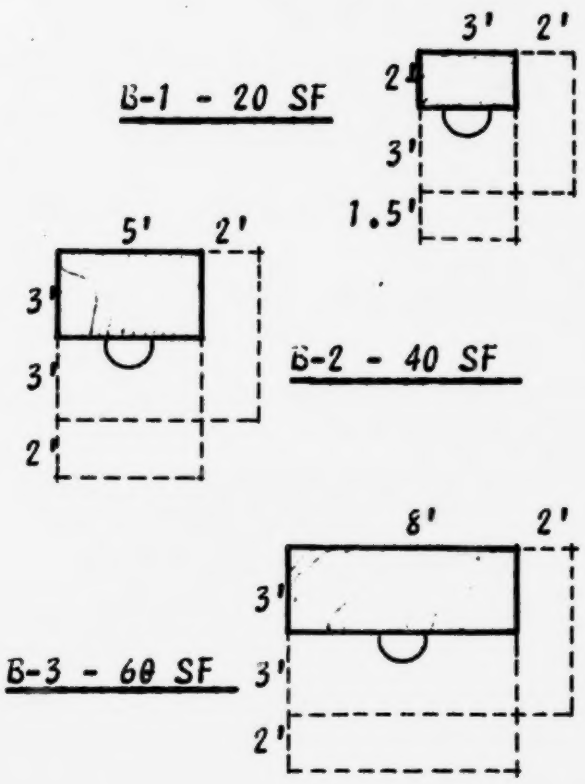


Figure A2: POSSIBLE ACTIVITY ZONES

ZONE C: SHELF STORAGE

activities: storage and retrieval of shelved materials, materials in shelf-sized cabinets, etc.

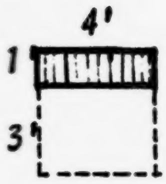
size variables: the number of lineal feet of shelving (projected on the floor).

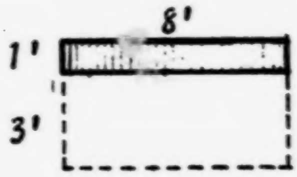
dedication: may or may not be shared.

compatibility: not accommodated separately unless security dictates, or unless a separate "library" is needed.

example alternatives: 3 are shown.

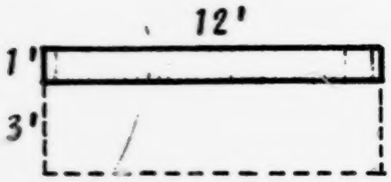
C-1 - 16 SF





C-2 - 32 SF

C-3 - 48 SF



ZONE D: FILE STORAGE

activities: storage and retrieval of materials from various types of filing devices.

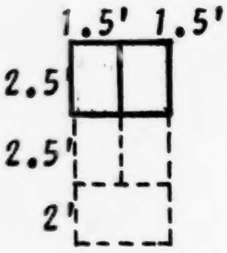
size variables: depends on the type and number of storage units. One approach is to assume standard upright files, and ask user to "translate" his file requirements in terms of these. Extra large units may qualify as Special Storage (Zone K).

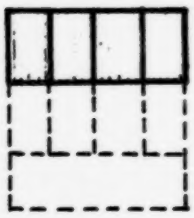
dedication: may or may not be shared.

compatibility: separate accommodation only for security or dead storage.

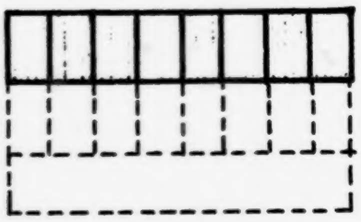
example alternatives: 3 are shown; user may translate his needs in terms of these or add his own.

D-1 - 20 SF





D-2 - 40 SF



D-3 - 80 SF

Figure A2: POSSIBLE ACTIVITY ZONES (continued)

ZONE E: WARDROBE

activities: storage and retrieval of coats, wraps, overshoes, etc.

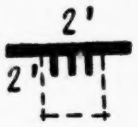
size variables: number of users; type of storage.

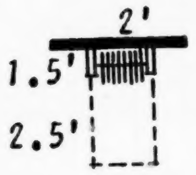
dedication: may or may not be shared.

compatibility: usually separated from other zones (in wardrobe or closet).

example alternatives: 3 are shown.

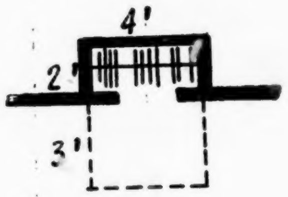
E-1 - 4 SF





E-2 - 8 SF

E-3 - 20 SF



ZONE F: INDIVIDUAL CONFERENCE

activities: reception of visitors, counseling, interviewing, personal dictation, discussion and other one-to-one situations.

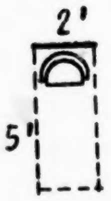
size variables: whether one or two chairs are provided (combination with other activity zones will assist in dictating this); arrangement and provision of table.

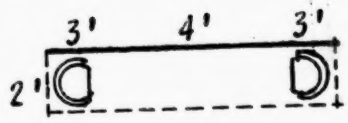
dedication: usually not shared.

compatibility: does not usually require separate accommodation from other activity zones.

example alternatives: 3 are shown.

F-1 - 10 SF





F-2 - 20 SF

F-3 - 36 SF

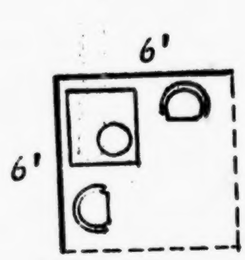


Figure A2: POSSIBLE ACTIVITY ZONES (continued)

ZONE G: SMALL-GROUP CONFERENCE

activities: reception of visitors, counseling, interviewing, committees, and other situations where 2 to 4 people participate.

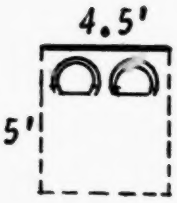
size variables: number of people involved; arrangement of furniture; whether or not a table is involved; combination with other zones.

dedication: may or may not be shared.

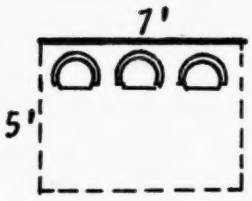
compatibility: may or may not require separate accommodation from other zones.

example alternatives: 3 are shown.

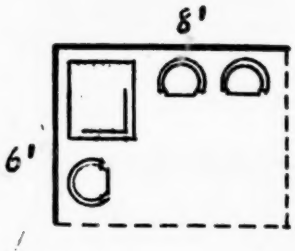
G-1 - 23 SF



G-2 - 35 SF



G-3 - 48 SF



ZONE H: MEDIUM-GROUP CONFERENCE

activities: discussion and meeting activities involving 4-10 people.

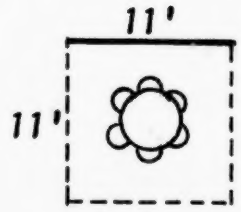
size variables: number and arrangement of participants; occasionally combination with other zones.

dedication: usually shared (except where office holders are important enough to warrant their own medium-group conference areas.)

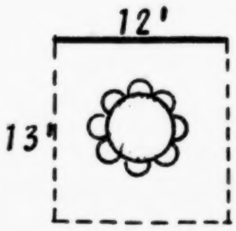
compatibility: usually accommodated separately from other zones.

example alternatives: 3 are shown; it may be possible to replace these by a sliding scale of factors which vary with the number of occupants.

H-1 - 140 SF



H-2 - 170 SF



H-3 - 200 SF

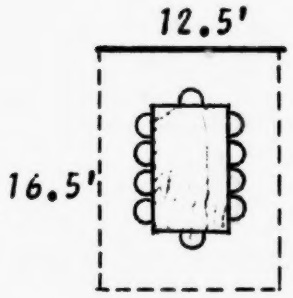


Figure A2: POSSIBLE ACTIVITY ZONES (continued)

ZONE I: LARGE-GROUP CONFERENCE

activities: discussion and meeting activities for 10 or more people.

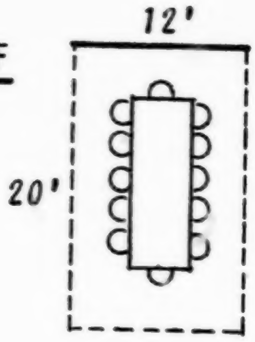
size variables: number and arrangement of participants.

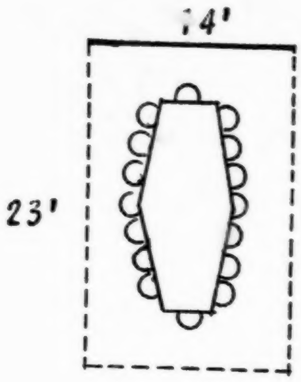
dedication: almost always shared.

compatibility: usually accommodated separately from other zones.

example alternatives: 3 as shown.

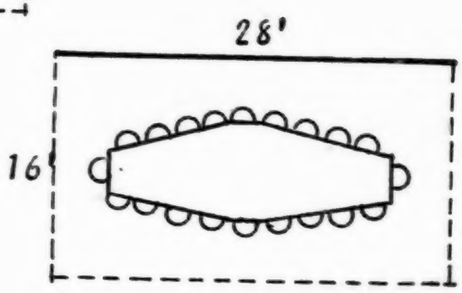
I-1 240 SF





I-2 - 320 SF

I-3 - 450 SF



ZONE J: SPECIAL WORK

activities: work area for office activities not in Zones A or B, such as drafting, blackboard and access, computer terminal, copying machine, etc.

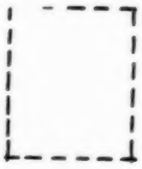
size variables: depends on type and amount of equipment or furniture involved; importance of special work station to office holders.

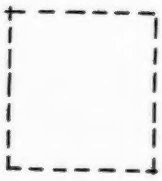
dedication: may or may not be combined with other activity zones.

compatibility: may or may not be accommodated separately from other zones.

example alternatives: a general selection of "sizes" would be provided with the individual user selecting (or creating) to suit his needs.

J-1 - 20 SF





J-2 - 40 SF

J-3 - 60 SF

Figure A2: POSSIBLE ACTIVITY ZONES (continued)

ZONE K: SPECIAL STORAGE

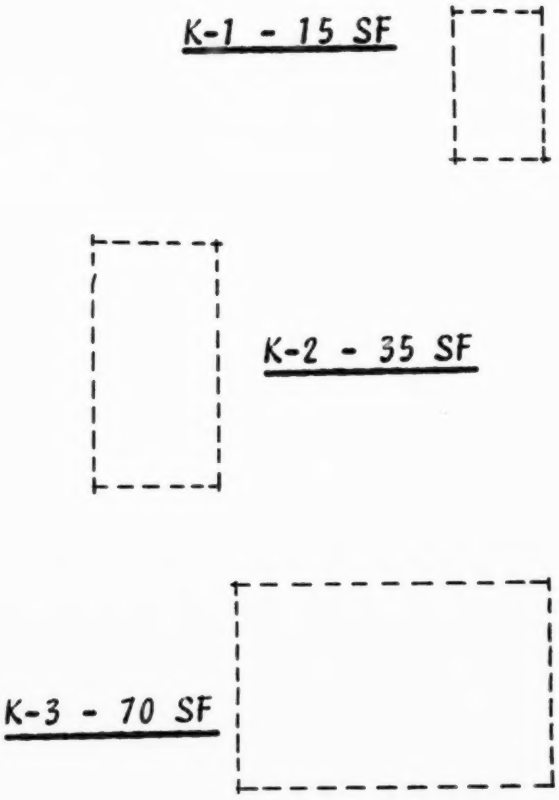
activities: special storage activities not included in Zones C-E, such as office supplies, special equipment, etc.

size variables: depends on type and amount of material stored.

dedication: may or may not be combined with other activity zones.

compatibility: usually accommodated separately from other zones.

example alternatives: A general selection of "sizes" would be provided with the individual user selecting (or creating) to suit his needs.



ZONE L: SPECIAL GROUP

activities: accommodations for group activities not included in Zones F-I, but which are still office-oriented; such as staff lounges, special reception and waiting areas, etc.

size variables: depends entirely on special activities proposed by user.

dedication: may or may not be combined with other activity zones.

compatibility: may or may not be accommodated with other zones.

example alternatives: A general selection of "sizes" would be provided with the individual user selecting (or creating) to suit his needs.

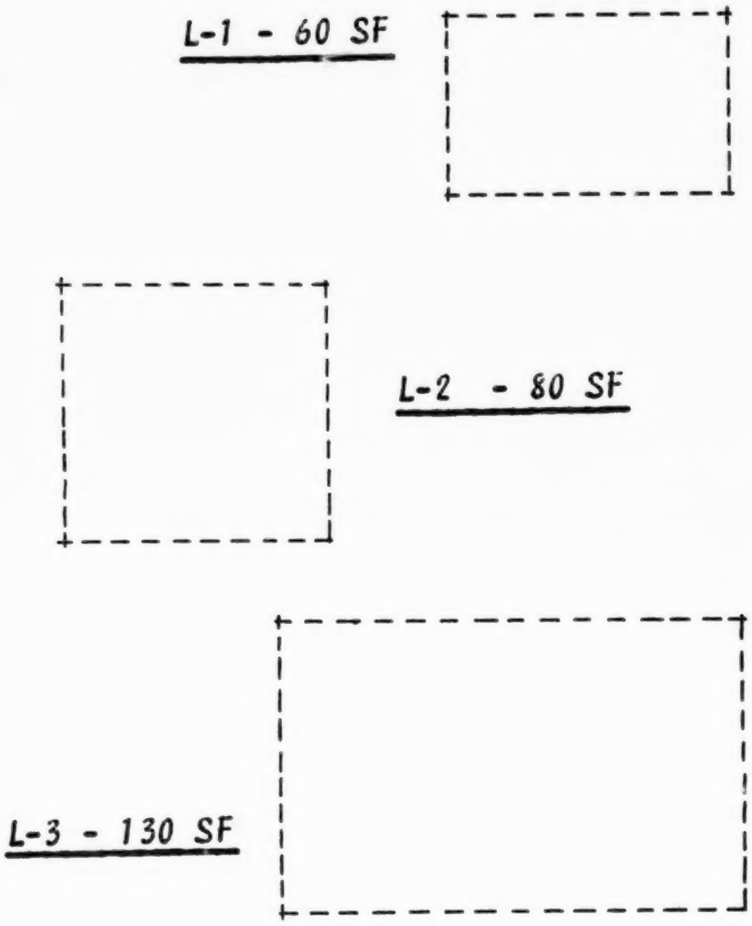


Figure A2: POSSIBLE ACTIVITY ZONES (continued)

more accurate sizes,

1. Paper designs, such as have been illustrated in Figure A2, should be developed as hypotheses.

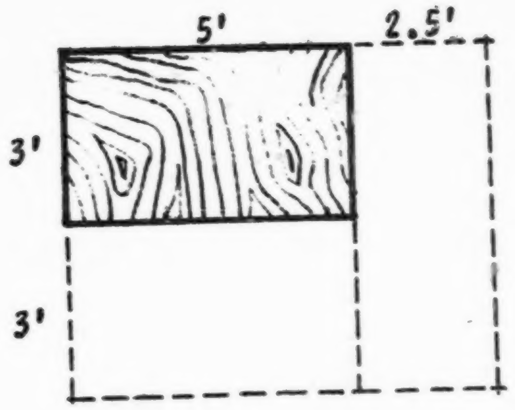
2. Existing office spaces should be divided into activity zones such as proposed here, and the zones should be measured. This will undoubtedly create many more "example alternatives" for each zone than are proposed here.

3. The "example alternatives" should be carefully examined, and where they can be combined, they should be. The system should face the user with as few choices as are possible without seriously limiting his flexibility of use.

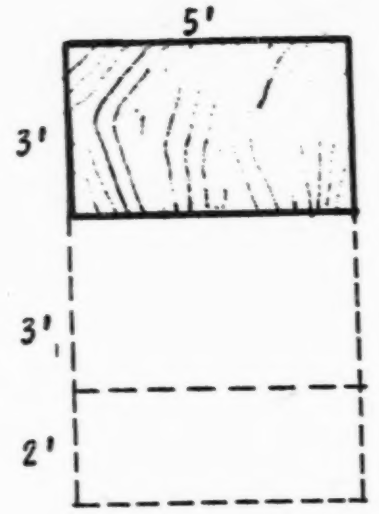
combining the activity zones into space

It is highly unlikely that any individual office holder will simply require one activity zone; most will require some combination of zones to house their specified activities. This means that the individual zones will have to be summed in some way to create a square footage for that officeholder.

This summation will not always be one of simple addition. Consider the case of faculty member X who requires a moderately-sized desk and adjunct work station. As can be seen in Figure A3, the two selected activity zones (A2 and B2) total 85 square feet. If they are combined as shown, they require 60 square feet of space to accommodate



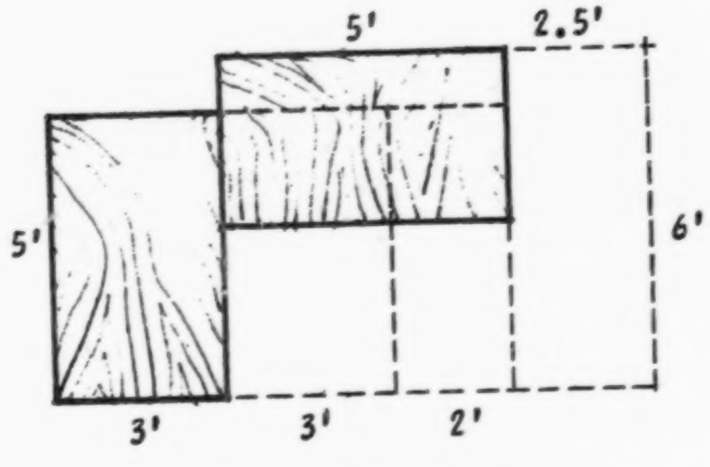
A-2 - 45 SF



B-2 - 40 SF

A-2 + B-2 = 85 SF

When two activity zones are combined, the required area is not always to be found by simple addition. Simply adding the required square footage for A2 and B2 suggests that 85 sf is required: as seen below, some arrangements may require less. In the example arrangement, only 60 sf are required to accommodate A2 and B2 in combination.



A-2 + B-2 = 60 SF

Figure A3: OVERLAPPING ACTIVITY ZONES

them.

This overlap comes from a basic assumption that one must include some circulation area in each of the activity zones -- it would be impossible to walk through an office crammed full of working and storage areas. As the various activity zones are combined, though, much of this circulation area overlaps and can be done away with.

How then does one accommodate this overlap? This is a question which requires a good deal of experiment and study. It may (or may not) include considerations of,

1. SPACE EFFICIENCY. There are any number of ways to physically combine activity zones. Some will take less space than others; some will take more. We cannot always deal with the very most efficient layout, however, for in doing this it is highly likely that we will place demands on adjacent elements which are so stringent that they cannot be met. As an example, it may turn out that offices for activity zones A2, B2, C1, D1, and E1 are most efficient if they are 10' x 12'. It is not always possible to endow every office with this "optimum" configuration without causing unreasonable increases in hallways, secretarial space, etc. In essence, not every space in a building can be equally efficient.

2. COMPATIBILITY. Two activity zones can be overlapped only if they can indeed exist side-by-side. If it is necessary to provide a Dean's work table in a separate room where his visitors cannot see it, it is unrealistic to figure an overlap with his desk (which is not in the same room at all).

3. DEDICATION. If an activity zone is not dedicated to a single user, then it may create implications for housing that zone: it must be accessible to every shareholder. This need for accessibility may affect compatibility between two zones and therefore the amount of space required.

4. PRIVACY. As one begins to combine activity zones and then place them in rooms, issues of privacy begin to appear. If any particular activity must be accomplished in a private fashion, this will begin to say things about compatibility of activity zones and where they must be accommodated.

The impact of all of these factors on square footage is not easy to assess. For this reason, it is necessary to outline one approach to combination. Following this, it will be necessary to carefully test and modify the approach as necessary.

The approach selected will be illustrated in some detail in the next section of the appendix. Briefly it revolves around selecting a relatively limited number of activity patterns, and then using the professional judgment of the systems developers to come up with various arrangements for these patterns. The arrangements are averaged, and the resulting square footage becomes an area statement associated with that pattern. A technique for allowing variations in the basic patterns is also included.

What this approach generally avoids is the issue of rooms: it treats space as just that -- space with no walls around it. It is hypothesized that the resulting loss of accuracy will not greatly damage the usefulness of the area statements -- as they will be reliable as the rest of the information used to run the system! The last section of the appendix, among other things, explores some considerations relating to "rooms" and outlines an approach for determining the impact of "rooms" on the area statements which will be initially placed in the system.

THE FRAMEWORK

introduction

This section of the appendix attempts to carefully present a framework which will accomplish a translation from "people" and "departments" and "activities" into area projections and requirements for budgeting and planning office facilities.

The tag "framework" is important. Since a general methodology for translating activities into space is generally lacking, it is the approach or the rationale which is important at this point. When it comes to the data needed to fill in parts of the framework, some of it comes from the user, and some of it resides in the system.

In terms of future research, it is the data which resides in the system that must concern the developers of the system. After the framework has been presented, the last section of the appendix will take up the question of this data and where it will come from.

a two-stage approach

The framework has been established as a two-stage operation. In the first stage the user initializes the system by inputting certain data about his institution; and then he and the system work together to jointly develop rules and techniques for determining activity patterns and assigning space within the institution. This stage is called "initialization" because a user will not have to repeat the process every time he uses the system. He may wish to refine it or take it to greater depths of detail as he continues to use it, but he will not have to regenerate basic data over and over again.

Once the system is initialized, it can be used in its second stage: space projection. Whether this projection is for long-range budgeting or short-range planning depends entirely upon the depth to which the user wants to go in generating detailed information about his institution. This will be more carefully analyzed after the framework has been presented.

the initialization stage

The initialization stage is particularly important. Since area statements for office and office-related facilities relate closely to the activities housed in these spaces, it is necessary that the system receive a picture of the user's institution, the kinds of office-holders, and some general rules for assigning space to these people. Because office-holders and space assignment guidelines will vary from institution to institution, it is impossible to pre-store them in the system.

Initialization cannot be a random process. The system needs this information to appropriately retrieve and assign area statements stored within it. Consequently, the system has a responsibility to guide the user through this stage.

Once initialization is reasonably completed, the system can be said to be personalized. It will reflect not only the administrative structure of the user, but also the policies used to assign space to people and academic/administrative entities within his institution.

Most users will go through this process once, and then use this as a point of departure whenever budgeting and planning are undertaken. Certain users, however, may wish to only partially initialize the system at the outset, reserving the right to complete the job each time the system is used for space projections. Still other users may choose to undertake initialization and space projection at one sitting. The option lies with the user. No matter which approach he uses, it is important that he understands one point: in initialization lies most of the basic planning decisions about office-holders and the assignment of space to them. This stage must be approached carefully and with a good deal of thought.

The initialization stage generally consists of two efforts: the determination of office-holders, and then the development of activity patterns and space assignment rules for them.

The number and type of office-holders have been generated in Operations 3.1 to 3.5 of the main portion of the model. Operations 3.6 and 3.7 shown here serve to reshuffle that information if this is necessary. The remaining operations explain the activity pattern and space assignment procedures.

In order to illustrate how this works, a running case study is developed in script type. It is by no means complete, but it will hopefully serve to illuminate and fill in the framework described in the text.

> *The example used to illustrate this framework in actual use is a small School of Architecture within a larger university.*
>
> *The School is divided into three academic/administrative entities: an Architecture Department, a Research Center, and a Dean's Office which oversees both operations.*

Each entity is somewhat self-contained, with its own reception and secretarial areas, offices, and associated support and conference functions.

operation 3.6 - select academic/administrative entities

The first step is to create a profile of the institution in terms of the various entities (colleges, schools, divisions, departments, centers, institutes, offices, administrative divisions, etc.) which comprise it.

Most of this work has already been done within the context of the main portion of the model. Academic departments and divisions have been established as part of Submodels 1 and 3. Operation 3.1 outputs faculty and research people by department; Operation 3.2 outputs students requiring offices by department; Operation 3.3 outputs a listing of administrative personnel.

It is possible, though, that the user may want to restructure this list for purposes of determining office space needs. He will want to make sure that it is complete (including, for instance, academic/administrative entities which may not have come up before, such as an Office of Continuing Studies), and that it accurately reflects the academic/ administrative structure of the institution.

There is a second reason for a possible restructuring at this point. It is expected that the system would include a pre-determined, rather generalized Catalog of academic/ administrative entities found at many colleges. Later in the space assignment stage, the system may be able to retrieve some general information on how other colleges approach space assignment within the entities listed in its own Catalog. The Catalog will also allow the system to store activity patterns by discipline where this is necessary. Wherever the individual user can relate to the systems Catalog, he will be in for additional benefits in terms of planning assistance.

> 3.6 In examining the Catalog of academic/administrative entity types in the system's catalog, our user locates "architecture". Using this general label may allow him to retrieve some planning data about "architecture" (as opposed to "chemistry" or "purchasing"), so he chooses to create three academic/administrative entities for his School, each labeled "architecture":
>
> ENTITY 1: ARCHITECTURE, ARCHITECTURE DEPARTMENT
> ENTITY 2: ARCHITECTURE, RESEARCH CENTER
> ENTITY 3: ARCHITECTURE, DEAN'S OFFICE
>
> note that the user needs to do this once and once only. Unless there is an administrative reorganization on campus, he probably will not need to come back and make changes.

operation 3.7 - selecting office-holder positions within the entities

Once the institution has been subdivided into its academic/administrative entities, office-holder positions must be assigned within them. Once again, this information can come directly from the earlier operations in the model,

- Faculty and research positions requiring offices, by department, from 3.1.
- Students in research positions requiring offices, by department, from 3.2.
- Administrative personnel positions requiring offices, from 3.3.
- Instruction and research-connected secretarial positions requiring offices, from 3.5.

The system will include a Catalog of positions within each of its entity types to assist the user in restructuring his information during this operation. While the user may not know it yet, each of the positions listed in the system's Catalog includes an associated pattern of activities which is often found with that position. If he wants to take advantage of these patterns, either directly for his own planning or as "basic" patterns to be modified by his own requirements (a more probable situation), it would be wise to use the positions in the Catalog wherever possible.

The depth of detail to which the user goes is largely in his hands. If he is uncertain, or if the types of office-holders within some of his entities are not yet determined, he may want to deal at a rather gross level. Biology includes 20 faculty positions. If he wishes to discriminate among these 20 positions, he may break them down into senior faculty, junior faculty, chairmen, research staff, counselors, and other classifications. This depends, to some extent, on what he wants to do with the data. As he moves into shorter-range planning, it is better to know more about a department than "20 faculty".

In any case, the user can always come back and refine this file of positions within his academic/administrative entities any time he wishes.

The kind of positions-within-entity Catalog which may be developed for the system is illustrated in Figure A4. It is by no means complete or even recommended; it is only one way of showing how it might be organized.

> 3.7 *The user, willing and able to discriminate among the kinds of office-holders in his School of Architecture, chooses to do so as follows. He uses the Catalog of positions to guide him in this chore.*

The following is presented as an illustration of how the Catalog of Positions-Within-Entities might be developed. The particular example shown here might be used to establish positions within any academic entity in a university.

LEVEL A broad category	LEVEL B rank or position		LEVEL C additional description
Full-time Faculty	Senior Faculty	Professor Associate Professor	Dean Chairman Administrative Assistant or Executive Officer
Part-time Faculty	Junior Faculty	Assistant Professor Instructor	
		Teaching Assistant	
Full-time Research Staff	Senior Staff	Professor Associate Professor Research Scientist, Engineer, Architect	Administrator Project Director
Part-time Research Staff	Junior Staff	Research Associate Research Assistant	
		Student Assistant	
Full-time Academic Support		Secretary Clerk Technician	Executive Dedicated Departmental
Part-time Academic Support			

In order to classify any office-holder by his position, the user simply selects the appropriate tags from each column. The number of tags he selects for any office-holder (or group of office-holders) will reflect the amount of detail he wishes to consider at any point. For instance, he may specify a full-time architecture professor who serves as an administrative assistant to his Dean in any of the following ways, depending on how much he knows about the position and whether it makes any difference (detail is less important in long-range budgeting):

Entity:	Architecture	Architecture	Architecture	Architecture
Level A:	F-T Faculty	F-T Faculty	F-T Faculty	F-T Faculty
Level B:		Sr Faculty	Professor	Professor
Level C:				Admin Asst

For each of these position specifications, it is hoped that the system would have stored an associated activity pattern. In accomplishing Operations 3.8 and 3.9, the user decides whether he wants to use the assigned pattern, use it with modification, or not use it at all.

Figure A4: ILLUSTRATION OF POSITION-WITHIN-ENTITY CATALOG

Entity 1: Architecture Department

F-T Faculty, Sr Faculty, Chairman
F-T Faculty, Sr Faculty, Counselor*
F-T Faculty, Sr Faculty
F-T Faculty, Faculty
P-T Faculty, Faculty
F-T Support, Secretary, Departmental

Entity 2: Research Center

F-T Research, Sr Faculty, Administrator*
F-T Research, Jr Faculty*
F-T Support, Secretary, Departmental

Entity 3: Dean's Office

F-T Faculty, Sr Faculty, Dean
F-T Faculty, Sr Faculty, Admin Asst
F-T Support, Secretary, Executive

* For purposes of illustration, it is possible that the starred positions were not in the system's Catalog. There may be no position called "Counselor"; and while there are positions called "Research Administrator" and "Research Staff" there may be no listing of these within an entity-type called "Architecture". Once the user perceives this, he knows that he and the system together will have to come up with space requirements for these people.

operation 3.8 - system assignment of activity patterns

Once a user-oriented file of office-holder types by position and academic/administrative entity has been created, the next steps are ones of associating activity patterns to these positions, and in some cases to the entities themselves.

There are two major problems in accomplishing this. The first revolves around the user. He is expected to be able to create appropriate activity patterns for many different kinds of office-holders. Some users will be knowledgeable enough to do this and do it well; many others will have problems of inconsistency and inaccuracy. To overcome this, it is suggested that the system pre-store activity patterns for as many positions in its positions Catalog as can be reasonably and accurately developed; when these positions come up, the system simply "assigns" its stored activity pattern to them. The user then reviews these patterns and modifies as necessary. Where he wishes to abandon system suggestions, or where he has created positions which do not exist in the Catalog (such as "Counselor, Architecture"), he leaves these for Operation 3.9.

There is a second problem, and this one revolves around the system. If there are twelve activity zones (see Figure A2), and if any office-holder may require any or all of these, it follows that the number of potential activity patterns is staggering. Because each of these activity patterns must ultimately carry a square footage with it, it is necessary to somehow limit the number of available combinations. On the other hand, this limiting process should not drastically constrain the user's flexibility in dealing with the system.

One approach is suggested here. It may not be the best; certainly it would have to be tested and modified in actual practice. The approach simply involves the development and sizing of a number of logical "basic" activity patterns -- and then associating these "basic" patterns with positions in the Catalog. From the "basic" activity patterns, the user and system can then construct "variations" together -- variations which recognize individual office-holder requirements.

The "basic" activity patterns would be created initially by the systems developers from their observation, recording, measurement, and general experience with office functions. These would then be schematically designed on paper (as illustrated in Figure A5). Various configurations would be attempted, and the results averaged.*

In Operation 3.8, then, the system simply "assigns" activity patterns to as many of the users positions as it can. The user then reviews this list on an item-by-item basis, and modifies it as necessary. Where his activity patterns differ greatly from those assigned, he simply creates a blank there and waits until he is ready to accomplish Operation 3.9.

To review, this "assignment" process brings two benefits to the user. It brings to bear experience of many people from many institutions, and it assists in maintaining an overall consistency throughout the files of office-holders and their activities. If the user wishes to completely disregard these "assignments", he may do so and proceed directly to the next operation.

> *3.8 Once the file of office-holders by position and academic/administrative entity is created in 3.7, the system is ready to assign whatever activity pattern it has stored in its own Catalog. The printout of these initial assignments might look like this:*

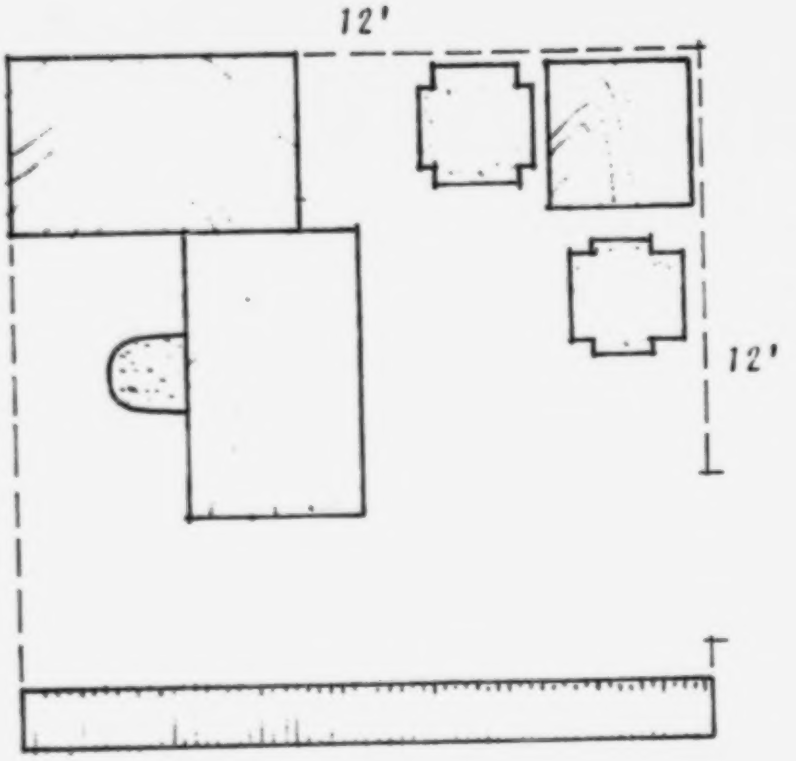
```
ENTITY  POSITION                  ASSIGNED
TYPE    TYPE                      ACTIVITY PATTERNS
.............................................................

(1:  ARCHITECTURE DEPARTMENT)

ARCH    CHAIRMAN, SR FACULTY      A2  B2  C2  D1  E1  G3
```

---

*It is obvious that this approach will create many configurations for one pattern of activities. Some of these will be exceptionally efficient in terms of area required, others will not. The averaging approach allows one to build in an "average" efficiency rather than a low efficiency (which would be wasteful of space) or a high efficiency (which is practically unattainable within every single space in a building).



A2 B2 C3 F3

scheme a -- 144 sf

One possible "basic" activity pattern might consist of the following zones: A2, B2, C3 and F3; provided individually, these activity zones would require about 170 sf. The two "paper designs" shown illustrate different ways in which these four zones might be combined; both schemes require 144 sf -- this figure would serve as a tentative area statement for this activity pattern.

A2 B2 C3 F3

scheme b -- 144 sf

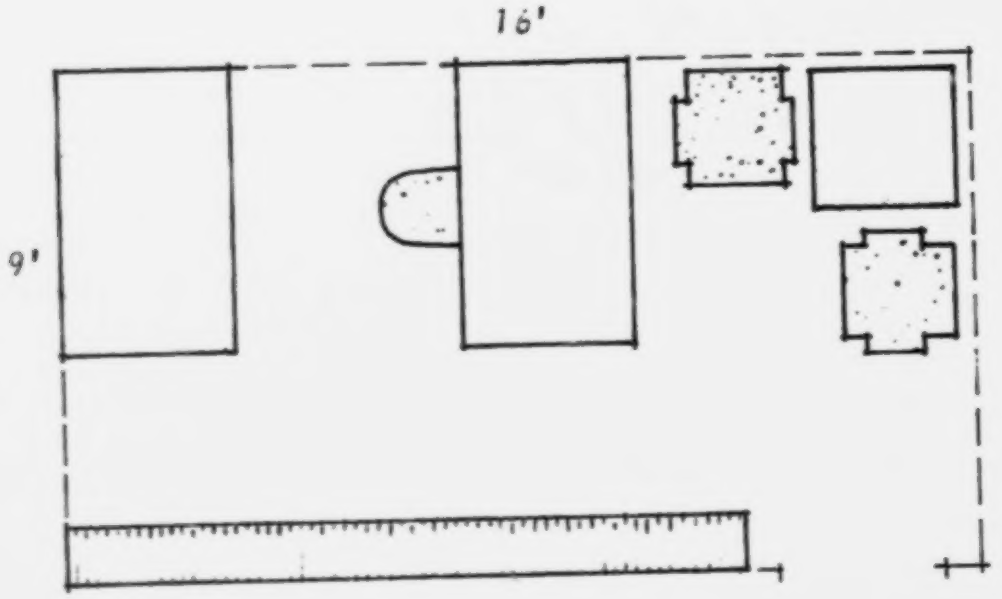


FIGURE A5: USING "PAPER DESIGNS" TO DETERMINE REQUIRED AREA

```
ARCH    COUNSELOR, SR FACULTY
ARCH    SENIOR FACULTY          A2  B1  C2  D1  E1  F1   J
ARCH    FACULTY                 A2  B1  C1  D1  E1  F1   J
ARCH    ADJUNCT FACULTY         A2      C1      E1  F1
ARCH    SEC, DEPARTMENTAL       A2  B2  C1      E1  F1

(2:  RESEARCH CENTER)

ARCH    RESEARCH, SR FACULTY
ARCH    RESEARCH, FACULTY
ARCH    SEC, DEPARTMENTAL       A2  B2  C1      E1  F1

(3:  DEAN'S OFFICE)

ARCH    DEAN                    A3  B2  C2  E1  G3  H3   J
ARCH    ADMIN ASSTS, FACULTY
ARCH    SEC, EXECUTIVE          A2  B2  C1      E1  F1
```

In looking over this output, the user notes that there may be some changes, either in activity zones or in alternatives within those zones, but he prefers to wait until he has filled in the blanks before attacking them.

operation 3.9 - complete activity pattern assignment

If the user is satisfied that the system's assignment of activity patterns is both accurate and complete, he will proceed directly to Operation 3.10. It is more likely, however, that he is either unsatisfied with some of the system's assignments (they do not recognize his own situation), and/or he has managed to create positions for which no assignment has been made. In these cases, the user and the system must sit down together and develop these patterns.

The user may approach the process of filling in the blanks in two basic ways: he can develop patterns on an item-by-item basis making decisions as he goes, or he may prefer to write some general rules which will cover many situations instead of one ("what distinguishes a counselor is a small-group activity zone").

This can and should be a highly interactive process. Some users will prefer to simply dictate activity patterns. If the system is appropriately developed, however, it can be of real assistance to the user in making appropriate and consistent decisions. It may assist him in formulating rules, it can flag decisions which appear to be incompatible with previous decisions, and it can assist him by bringing forth research findings and experience of other users ("a 1966 survey of 27 Schools of Architecture noted that 90% of their faculty possessed dedicated drafting stations").

The system will also attempt to keep the user operating within its own set of "basic" activity patterns whenever possible. When this cannot happen, it can present the user with graphic and square footage information on various alternatives, assisting him in selecting appropriate activity zones.

These kinds of capabilities will not be easy to develop; certainly they have not yet appeared on the scene. Careful research within the framework established here would do the job, though.

> 3.9 In examining the activity assignments of 3.8, the user notes that there are some blanks which need to be filled in; he also recognizes some inconsistancies with respect to his own School and its needs.
>
> He seeks to remedy the situation through a series of actions, some designed to include many office-holders, others on an item-by-item basis. It might take this form:
>
> 1. He notes that only some faculty are provided with drafting stations (designated as special work station, "J"). Because it is a long-standing policy of his School that all faculty be provided with drafting space, he directs the system to add a "J" to the file of each office-holder tagged "Faculty". In doing this, he may query the system for re-

search findings and experience of other schools in doing the same thing.

2. He attempts to derive an appropriate activity pattern for the position of "Counselor, Senior Faculty". He might start by calling the pattern for "Senior Faculty":

```
    SR FACULTY               A2   B1   C2   D1   E1   F1   J
```

It occurs to him that the distinguishing characteristic of a Counselor is his need to meet small groups in his office as well as individuals. He suggests modifying the pattern to,

```
    COUNSELOR, SR FACULTY    A2   B1   C2   D1   E1   G3   J
```

In terms of the system's sizing this activity pattern, there may be a problem. If the user asks the system whether or not it is a previously stored pattern, and the system says "no", the user has two choices: alter it until it fits a stored pattern, or attempt to work with the system to size the new pattern. Believing that the "Counselor" pattern will not fit any existing in the system, the user calls for the two closest. In doing this, he might retrieve,

```
   CHAIRMAN, SR FACULTY      A2   B2   C2   D1   E1   G3   J
                                  ↓
 ( COUNSELOR, SR FACULTY     A2   B1   C2   D1   E1   G3   J )
                                                      ↑
   SENIOR FACULTY            A2   B1   C2   D1   E1   F1   J
```

He now has two ways of approaching the intermediate pattern: take the square footage size associated with the Chairman and reduce the "B2" to a "B1" (here the system displays a picture and description of each to assist in making the reduction); or take the Senior Faculty square footage and translate its "F1" into a "G3". Most likely the user will do both and if they do not come to the same general square footage, he will exercise his judgment in making a projection.

3. The same pattern can be followed for the Research Staff. The user may wish to generate an entirely new activity pattern, or he may attempt to use or modify an existing one. In either case, he has to find a way of determining square footage requirements for the pattern he selects.

4. The same approach is followed with the Administrative Assistant.

The results of these explorations will be printed out for *the user's review and modification. Any time he wants the system to give him the associated area statement for any actual pattern, the system will do so.*

operation 3.10 - associate activity patterns with acadmic/administrative entities

Referring back to the discussion of office and office-related activities in the second section of this appendix, it is now obvious that the previous operations have covered most of the "office" activities. To the extent that conference and clerical support functions have been included, there has also been partial consideration of the "office-related" activities.

Many of these "office-related" functions are not directly (or always even indirectly) associated with individual office-holders; sometimes they are more logically associated with the academic/administrative entity as a whole. These might include,

- large-group conference activities
- medium- and small-group conference activities not particularly associated with or dedicated to one particular office-holder.
- special work stations which are department-associated (copying machines, etc.)
- reception and waiting area for the entity.
- special storage space for the entity.

It is therefore suggested that it should be possible for a user to associate some activity zones with the entity as a whole. In terms of sizing these zones, it may not be particularly important to know whether they will all exist in one place (and therefore overlap), or whether they will take place in several rooms. What is developed is an overall figure which represents a summation of the special entity-associated zones; this figure is expressed as a "pool" of space needed to generally serve the entity. When the user moves from short-range planning into actual building programming, he can look back to see what generated that pool and then actually allocate the space to rooms.

Because it may be more difficult to precisely determine needs for entity-associated space, it is highly likely that users will develop rules; for example, the user may say, "For every professional faculty or staff member in any entity, allow 20 square feet of activity zone I: Large-Group Conference". This rule does not say whether this will end up as one large room or two smaller ones; it simply places so many square feet of space into the entity-associated pool.

> 3.10 *The user decides to associate reception, filing, special work and storage space to each of his three entities, probably using some institution-wide projection rules.*
>
> *Based on these additions, and the changes made in Operations 3.9, his final output of activity patterns for the School may be as follows:*

```
ENTITY   POSITION                ASSIGNED
TYPE     TYPE                    ACTIVITY PATTERNS
..............................................................

(1:  ARCHITECTURE DEPARTMENT)

ARCH     CHAIRMAN, SR FACULTY    A2   B2   C2   D1   E1   G3   J
ARCH     COUNSELOR, SR FACULTY   A2   B1   C2   D1   E1   G3   J
ARCH     SENIOR FACULTY          A2   B1   C2   D1   E1   F1   J
ARCH     FACULTY                 A2   B1   C1   D1   E1   F1   J
ARCH     ADJUNCT FACULTY         A2        C1        E1   F1   J
ARCH     SEC, DEPARTMENTAL       A2   B2   C1        E1   F1
ARCH     ENTITY #1 - ASSOC.                     D2   H1   H3   K  L
```

```
(2:  RESEARCH CENTER)

ARCH      RESEARCH, SR FACULTY  A2   B2   C2   D1   E1   G2    J
ARCH      RESEARCH, FACULTY     A2   B2   C2   D1   E1   F1    J
ARCH      SEC, DEPARTMENTAL     A2   B2   C1        E1   F1
ARCH      ENTITY #2:  ASSOC                    D2   E2   H1    K    L

(3:  DEAN'S OFFICE)

ARCH      DEAN                  A3   B2   C2   E1   G3   H3    J
ARCH      ADM ASST, FACULTY     A2   B2   C2   D1   E1   G2    J
ARCH      SEC, EXECUTIVE        A2   B2   C1   E1   F1
ARCH      ENTITY #3:  ASSOC                    D2   E2         K    L
```

Note: At this point it is possible to provide an associated square footage at the ends of each of the items printed above.

completing initialization

When the user can generate a satisfactory output such as the one shown above, he has completed the initialization process. As has been suggested above, it may not be this simple though. He may undertake a series of successive iterations, constantly cross-comparing decisions and their resulting influences on space. Hopefully, he accomplishes these iterations in a highly interactive way, allowing the system to assist him at every turn. The decision-making authority, however, is always in the user's hands.

Figure A6 summarizes the steps involved in this initialization procedure.

the projection stage

Once the user has initialized the system, he has made most of his basic planning decisions. The system now reflects his institution, both in terms of its administrative structure and the rules it uses in assigning space to people and groups within that structure.

(input)	(operations)	(parameters)	(output)
Operation 3.6: Select Academic/Administrative Entities			
academic/administrative entities listed in previous operations.	restructure list of entities to cover institution; adhere to tags in system catalog whereever possible.	appropriateness of catalog tags to entities in the institution.	list of academic/administrative entities in the institution.
Operation 3.7: Select Office-holder Positions Within the Entities			
list of academic/administrative entities from 3.6. list of office-holder types from previous operations (3.1, 3.2, 3.3, 3.5)	develop set of office-holder positions within each entity; adhere to tags in system catalog wherever possible.	appropriateness of catalog tags to positions listed by the user.	list of position types within each of the academic/administrative entities in the institution.
Operation 3.8: System Assignment of Activity Patterns			
list of position types within each academic/administrative entity, from 3.7.	system looks up position types in its catalog and retrieves associated activity pattern (and area statement) for each one listed. where positions do not exist in catalog, no activity pattern is listed.	automatic step: activity patterns developed by professionals and modified by experience.	list of position types within each entity, along with an associated activity pattern if there is one in the system. areas for patterns in the system can be retrieved if desired.
Operation 3.9: Complete Activity Pattern Assignment			
list of position types within each entity, along with associated activity patterns, from 3.8.	create activity patterns for positions where system has not assigned them. modify system-assigned patterns and associated square footages as desired.	appropriateness to user's situation. adherence to basic pattern types already stored in the system wherever possible.	same as 3.8, except that list is now complete.
Operation 3.10: Associate Patterns With Academic/Administrative Entities			
list of entities and positions within them with patterns assigned from 3.9.	add entity-associated patterns.	appropriateness to user's situation; complementary to patterns associated with office-holders.	complete list of activity patterns by entity and position; square feet may be included.

Figure A6: SUMMARY OF INITIALIZATION PROCEDURE

Now he is ready to actually project space needs. Because the basic groundwork is already laid, however, this projection process is a rather simple one.

It simply begins with an assignment of head count information to the various position-within-entity categories developed as part of the first stage. When these are all assigned, the area statements for each of those categories (also developed in the initial phase) are retrieved; simple multiplication and summation are then used to develop overall space requirements.

These operations are so straightforward that careful explanation and discussion is unnecessary. Figure A7 on the next page explains Operations 3.11 through 3.13 which comprise this stage.

long-range budgeting versus short-range planning

So far there has been very little emphasis on the differences in use of this framework as the user moves from long-range budgeting to short-range planning. Nor should there be. The difference between the two modes is not one of objectives (both look forward to area statements); the difference is one of data detail and accuracy.

In the long-range budgeting mode, the user is essentially interested in determining large "pools" of space, undifferentiated by anything resembling buildings or rooms. He inputs information which is relatively undefined, and receives back results which reflect this kind of input. Since he cannot spell out every detail, both the user and the system operate at a level where there are many assumptions and where there is a good deal of averaging.

(input)	(operations)	(parameters)	(output)
Operation 3.11: Associate a Head Count With Each Position-Within-Entity			
list of position types within each academic/administrative entity, from 3.7. head counts for these positions from operations 3.1, 3.2, 3.3, and 3.5.	restructure head counts to fit position types in input from 3.7.	appropriateness of head count with positions.	list of position types with each entity, with a head count figure entered with each.
Operation 3.12: Determine the Total Area Required for Each Position-Within-Entity			
list of position types within each entity, with head count figures entered for each. area statements developed for each position-within-entity, from 3.9.	simple multiplication.		list of position types within each entity, with an associated area statement (square feet required) for each.
Operation 3.13: Determine Total Area Required for Each Entity			
list of position types within each entity, with associated area statements, from 3.12. area required for entity-associated activities, from 3.10.	simple addition.		summation of area required for each entity. Both in total square footage, and in square footage broken down by positions and "pool" space.

FIGURE A7: SUMMARY OF SPACE PROJECTION PROCEDURE

For short-range users, the user can go back through the initialization process, refining and discriminating among the rather large "packages" of information placed there when he was budgeting. Once more is known about people and their activities, the system can react with more accurate and meaningful area statements.

Figure A8 goes back through Operations 3.6 to 3.13, explaining how they might be accomplished in both long- and short-range modes of operation. As one can see, the differences lie in the kinds of information and statements available, rather than in any fundamental variance in approach.

moving from short-range planning to programming

The "final" institutional action in creating university facilities is the writing of detailed building programs. These programs carefully analyze user activities and, among other statements about environment, include area requirements for each function.

What has been developed here is not a programming tool. True, it can serve as a programming device (i.e., in short-range planning), and it can be used to check program statements (thus identifying gross errors in the program), but it should not be used to develop the program.

Why? At this point, the system is still talking about chunks of space ("120 square feet" of floor area); it has said little about actually translating this area into rooms, and this is an important step. It is one task to associate required square footages with professors and administrators and secretaries, and it is quite another task to enclose these in rooms:

(long-range budgeting)	*(short-range planning)*
Operation 3.6: Select Academic/Administrative Entities	
May well be dealing with academic and administrative entities on rather broad levels. May use "schools" and "colleges" in place of departments, sub-departments, program-within-departments, multi-disciplinary academic efforts, etc. Very likely to combine many administrative and support activities into broad categories ("academic administration", business administration", "student affairs", etc.) rather than specific divisions and offices.	*Will be able to subdivide institution into its real structure of academic and administrative entities, including all of its colleges, schools, divisions, departments, centers, institutes, sections, offices, support sections, etc. This allows the user to break the large "pools" of space developed in long-range budgeting down into manageable collections for planning.*
Operation 3.7: Select Office-Holder Positions-Within-Entities	
If the entities cannot be carefully broken down, it follows that the user will not be able to carefully identify the various office-holder positions within them. For this reason, he may stick to titles such as "faculty", "faculty administrators", "administrator", "clerical", etc.	*Office-holder types can be broken down into more specific groups.* *(The actual level of detail will relate very closely to that developed for the main portions of Submodels 1 and 3).*
Operation 3.8: System Assignment of Activity Patterns	
The system's Positions-Within-Entity Catalog contains different levels of position definition (see Figure A4 for an example). Activity patterns can be associated at gross levels as well as defined levels; the user must, however, recognize that these are necessarily averages -- that they may vary quite a bit when the position types are more fully defined. Averages work for long-range budgeting.	*Activity patterns are best assigned to Positions-Within-Entities which are relatively well defined. An institution working at this level should be able to expect rather accurate results.*

Figure A8: USING THE MODEL IN THE TWO PROJECTION MODES

Operation 3.9: Complete Activity Pattern Assignment

(long-range budgeting)	(short-range planning)
This operation is rarely carried out in long-range budgeting uses. Users will confine their Positions-Within-Entity selections to rather broad types, and it is expected that there will be associated area statements for each of these.	The user knows enough about his highly specialized or out-of-the-ordinary Positions-Within-Entities to create intelligent activity patterns for them.

Operation 3.10: Associate Patterns With Academic/Administrative Entities

In the long-range planning mode, it may be possible to approach this from a historical viewpoint: "historically, how much entity-associated space (in terms of percentage) do we find in Schools of Architecture?" Until this is feasible, the user will have to make some intelligent guesses about entity-associated activities.	The more the user knows or cares to project about any entity and its operations, the better position he is in to identify entity-associated activities and their area requirements.

Operation 3.11: Associate A Head Count With Each Position-Within-Entity
Operation 3.12: Determine the Total Area Required for Each Position-Within-Entity
Operation 3.13: Determine Total Area Required for Each Entity

The level of detail generated will depend entirely on the level of detail created in the preceding steps. It is probable that the output from 3.13 will be a total area required for each entity, with no further breakdown.	The level of detail created in the above should allow detailed analysis and output. Resulting lists should be able to detail not only total area requirements for each entity, but it should also be able to break them down by position type within that entity. There is one caution to be noted here, however. These results, even when broken down by position type, should not be used in detailed building programming without further examination. See text.

Figure A8: USING THE MODEL IN THE TWO PROJECTION MODES (continued)

how many professors to a room? should a professor share an office with an assistant? These are important questions which the framework, as developed to date, leaves unanswered. This is discussed again in the next section of the appendix.

FUTURE DIRECTIONS

improving the technique

The foregoing portion of this appendix has proposed one technique for taking people, their positions and departments, and translating them into required space for purposes of budgeting or planning. This technique has been developed from the realization that most traditional "survey-what-space-people-have-and-come-up-with-a-standard" approaches all have certain weaknesses. The proposed technique starts with the office and office-related activities people undertake and attempts to derive area statements which reflect and accommodate these activities.

Because the approach has been somewhat unconventional, it has been characterized by a good deal of tentativeness: this is what we should try, and here's what it might do. The next step is to explore these "shoulds" and "mights", converting them into "musts" and "wills".

This will not be a simple effort. Rather a good many facets of the space projection problem will have to be examined, people will have to be interviewed, and their activities will have to be observed before a truly positive and accurate framework is possible. Based on what has gone before, five issues can be established as focal points for future work,

1. Developing appropriate activity zones.

2. Developing and refining activity patterns.

3. Establishing the effects of placing activities in "rooms".

4. Establishing the effects of other factors on size.

5. Extending the approach to the other facilities submodels.

developing appropriate activity zones

Since the "activity zone" has been proposed as the concept which translates people and activities into space and square feet, it is important that it be carefully thought out and applied.

In the second part of the appendix, office and office-related activities were listed, and twelve activity zones were created. For purposes of illustration, each of the twelve zones was further subdivided into "example alternatives".

Each of these steps in the creation of the activity zones requires further research. Listing office activities raises no problem, but their combination into "zones" of space should be carefully looked at. Should there be twelve of these zones? or five? or twenty? Certainly any reduction in the number of zones will make the system less cumbersome -- but what limitations might this place on user flexibility?

Once the zones are established, their sizing becomes another issue. How many alternatives should there be, and how much area does each reasonably consume? As suggested before in this appendix, this entails a careful analysis of what people do in university offices, and how much space they use in doing it. This will require an active program of observation, measurement, interviewing, hypothesizing activity zones, designing these zones, mocking-up alternatives, evaluation of alternatives, and modification or reformulation of proposals.

This kind of activity can and should be a continuing one. An initial version of the system can be established with the zones proposed in this document (or some refinement of them); as experience is gained, both with office activities and with system use, the activity zones, their alternatives and their sizes can be continually modified by professional personnel.

developing and refining activity patterns

The proposed framework assumes that one can associate an appropriate "pattern" of activity zones with any office-holder once his position and his entity are established. This need for assigning patterns (with user modification, of course) is an important one if we are to limit the number of patterns which actually have to be carefully sized.

This too requires additional research and experimentation. Can we deal with "basic" activity patterns for various office-holders, or is this a hopeless cause? If we can develop "basic" patterns, can we develop rules for making variations, or is it necessary to take the stand that any variation may produce inaccurate projections? Once we settle on activity patterns, can we provide an associated square footage that is accurate enough to make projections with?

The first two issues will be resolved through more detailed observation and analysis of university office-holders and the activities they undertake. The third issue -- that of sizing activity patterns -- is more complicated. This will require a co-ordinated research effort to schematically design the various ways of putting any given set of activity zones together, to mock these up and test them in practice, and then to pick an "average" square footage which does not dictate excessive waste or excessive efficiency of planning.

establishing the effects of placing activities in "rooms"

The framework presented in this appendix treats space as just that: space, without intervening or defining walls, doors, and other architectural elements. This is admittedly a potential weakness in the sense that the resulting area statements may not be as valid as they could be if the walls were included.

Why? The effect of placing walls and defining rooms is to carefully control the overlaps among the activity zones. If a Dean's set of activity zones is to be accommodated in three rooms instead of one, it is obvious that they cannot all overlap. Conversely, if two office-holders and their activity patterns are accommodated in one room, there may be some overlaps between their respective patterns as well as within them. Each of these statements suggests that the total number of square feet required by each office-holder may differ according to its division (or combination) into "rooms".

The effects of placing these zones in rooms will have to be carefully tested before any system is finalized. The approach at this point has been to disregard them; to assume that at the level of accuracy required (even in short-range planning) these effects will balance each other.

In terms of looking at single office-holders and allocating their activity zones into "rooms", there is one technique which can be used within the framework presented here: that of simply considering the office-holder as possessing not one, but a number of sets of activity zones. For example, an Architecture Dean with the following pattern,

A2, B2, C2, E1, G3, H3, J = w sq. ft.

might be respecified with these three patterns,

A3, B1, G3 = x sq. ft. Office
B1, C2, J = y sq. ft. Work Room
H3 = z sq. ft. Conference

If this can be accomplished, it is not important that the sum of x, y, and z may not equal w. To do this, though, raises a whole set of questions about compatibility of activity zones, privacy required by activities, and which activities are dedicated to specific users and which are not. The question becomes whether it is necessary or even appropriate to raise these issues in space planning and projection. Only experiment and experience will provide the answer.

Once a user moves into allocating office activities to rooms, he raises another thorny question: that of multiple-occupancy offices. In some research and clerical situations, these are not difficult questions. When it comes to faculty and administrators, however, it can be equated to opening Pandora's box. In dealing with these positions, office accommodations often take on the quality of "fringe benefits", and consequently they are often surrounded with well-worn and time-honored tradition and policy.

Further, the kind of office a professional staff member is provided may well dictate (or at least influence) the amount of time he spends in it, how available he is to students and colleagues, how effective he can be in discussing personal problems and issues, and how determined he can be in undertaking his academic, committee and research tasks. The success of the shared office usually depends strongly on the congeniality of the partners, and this is a difficult commodity to assess during long-range planning.

The issue of space economy through multiple-occupancy is another knotty one. Some administrators assume that a three-man office (because of the activity overlaps) can be smaller than three one-man offices. Others will contest that to be truly effective in a "bullpen", staff will try every technique to attain privacy and get away from each other, thus consuming additional space.

The allocation of office activites to rooms, then, becomes an odd and often explosive mixture of quantitative factors and qualitative considerations. The model used to translate people and activities into this space must allow the user to first superimpose his own policy. Then it must react by translating the policy into square feet and by constantly reminding the user of its "activity" orientation. The system simply cannot be asked to rule on the effectiveness of the one-man office versus the three-man office.

establishing the effects of other factors on size

The previous discussion has suggested that a person's activities may not be the only determinant of the area he requires. In some cases the factors are more qualitative and relate to his position or situation rather than the activities he actually undertakes. The only way the system can account for these is to let the individual user override its suggestions.

There is an entire second class of factors which are more difficult to manage. These include other environmental factors which tend to influence size or people's perceptions of size. Windows and vision panels to borrow light and views (and hence psychological "space") from other areas can serve to make a space "feel" larger. The strategic location of doors, radiators and other "protrusions" into a room may seriously limit layout possibilities, making a space seem smaller to the user. Poor acoustics, hard surfaces, odd configurations, excessive heights, and many other factors can influence reactions to size.

These factors become particularly significant in smaller rooms. Let's look at a clerk who, according to a listing of his activities, requires fifty square feet of space. If for some reason that fifty square feet must be placed in a single room, one can begin to question whether the occupant will be able to actually function in that space. If the room has generous visual access to the outdoors or even to other spaces, it is possible that the small size of the room is no problem; if the same area is provided between four concrete block walls and is fifteen feet high, the place may be uninhabitable.

This suggests two hypotheses,

1. There may indeed be a "minimum size" for an office station; an area which should not be reduced even if the activity patterns call for it; but that,

2. This "minimum size" will probably depend on a number of other environ-

mental conditions.

At this stage, it is impossible to truly cope with these issues. More research in physical environment and its psychological effects on its occupants must be undertaken.

extending the approach to other facilities submodels

What has been developed in this appendix is a specific technique for translating office and office-related activities into office and office-related space. There is much about the approach which can be applied to other facility types within the university; undoubtedly there are concepts which cannot.

In parallel with improving the office facilities framework, it will be necessary to extend this activity-oriented thinking to the other submodels in the system. Each will have to be analyzed on its own merits. Some submodels may allow a translation which is less complex than that developed here; others may require an even more detailed effort.

To a certain extent, however, efforts in the other facility types will be complicated by the same general problem which has been seen throughout this entire appendix; the lack of established appropriate methodologies which translate human activities into space requirements and then abstract these requirements to the point where they can be effectively used in space budgeting and planning.

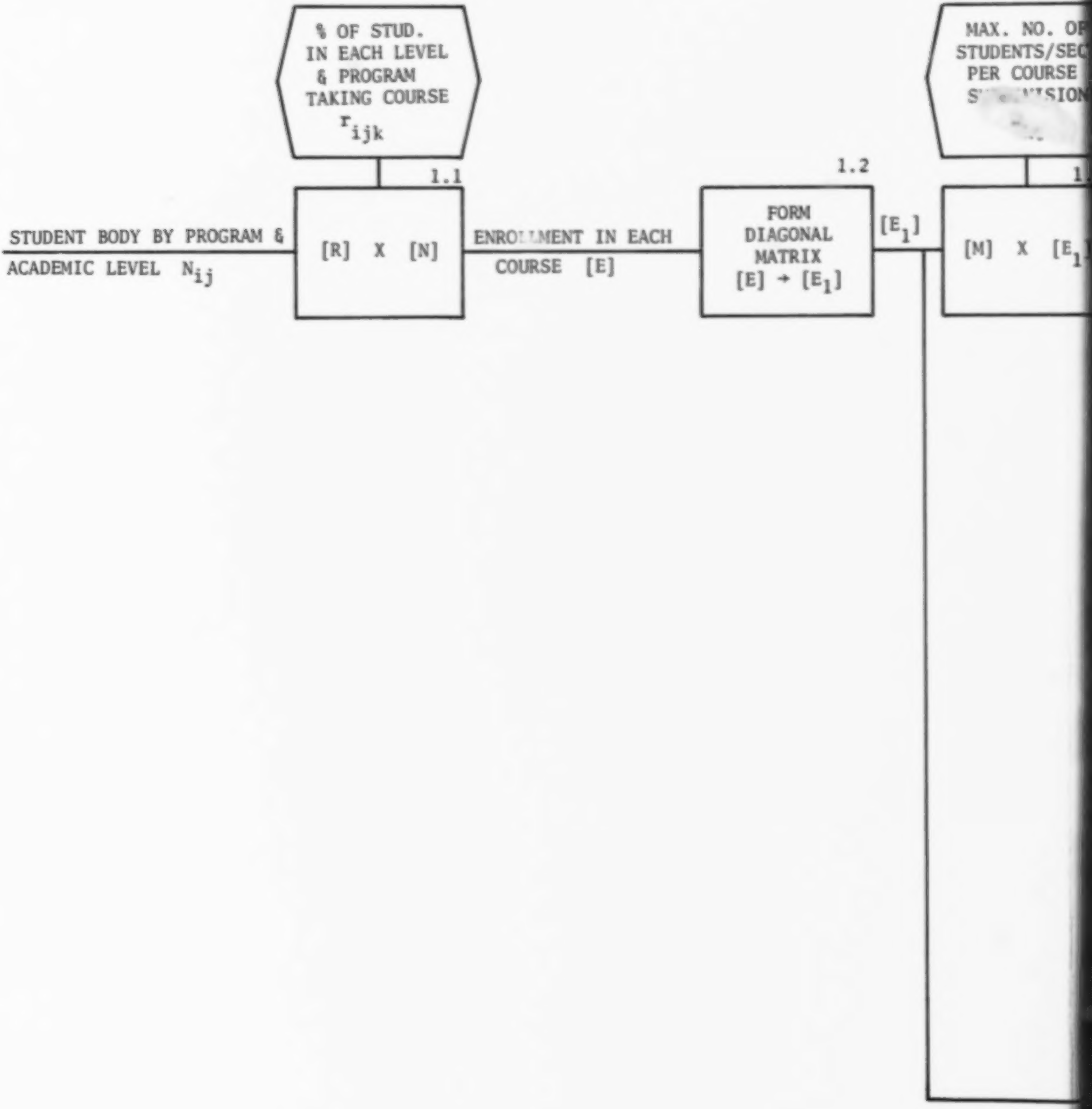
in summary

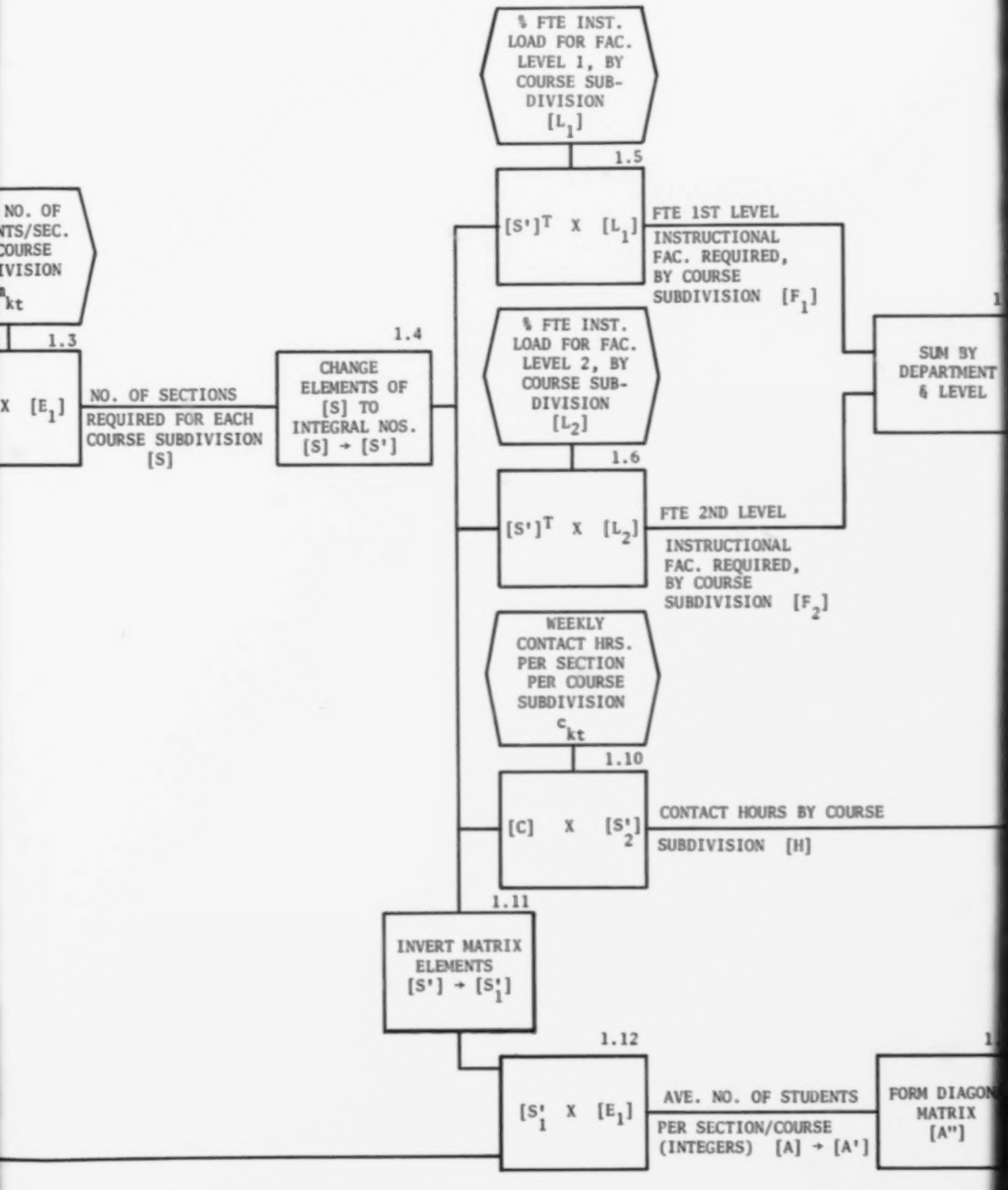
It was evident from the start of the small study which produced this appendix that the issue was too large and too complex to instantly create "area statements" which were both accurate and appropriate. Statistical summary of existing space-use data could have produced some very fine numbers, but these numbers would have borne only incidental relation to human space needs.

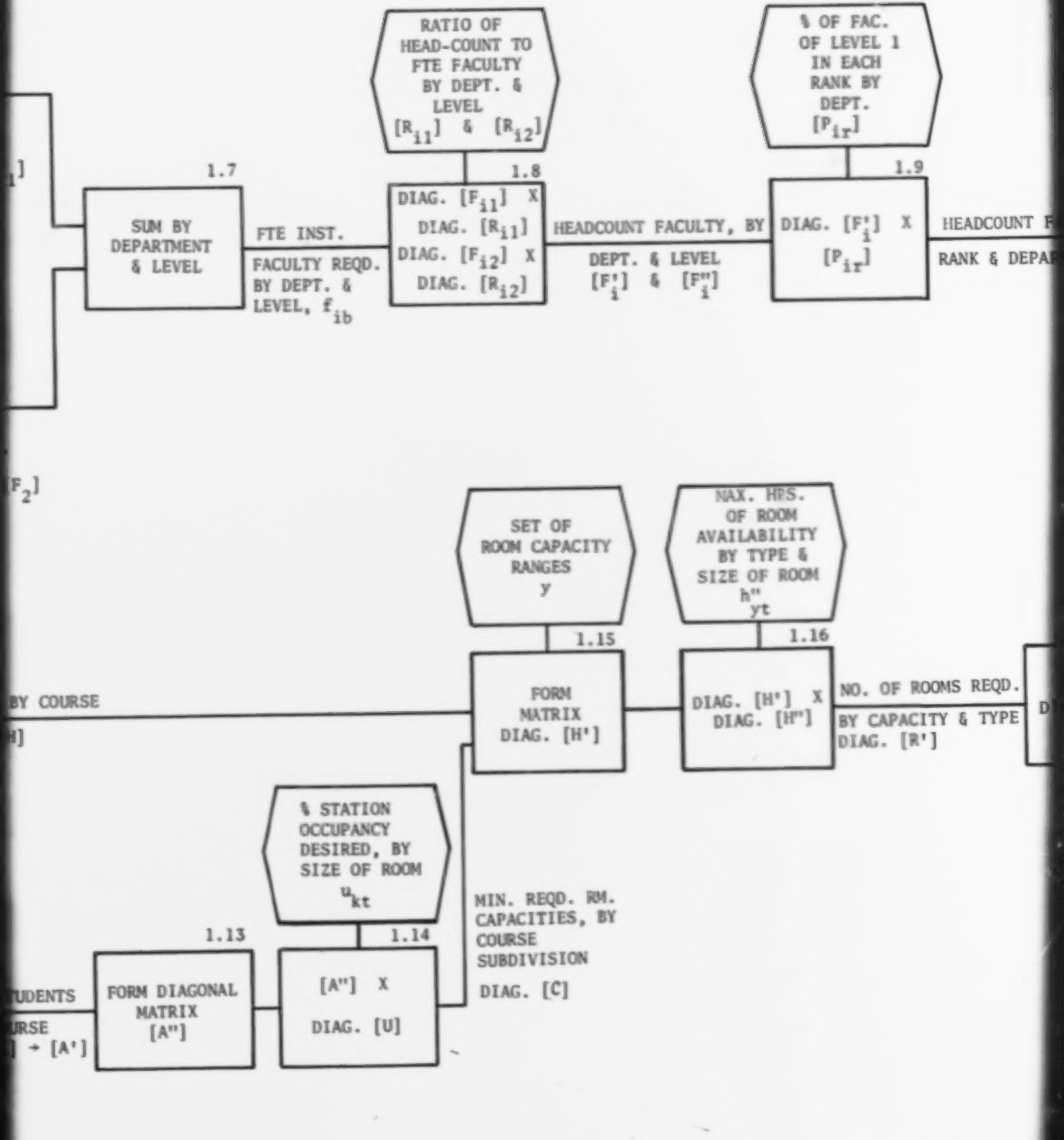
In the long run, it is possible that the detailed, start-with-the-activities approach outlined here is unnecessary for space budgeting and planning; that the whole process is so inexact that it makes no sense to use carefully developed space factors.

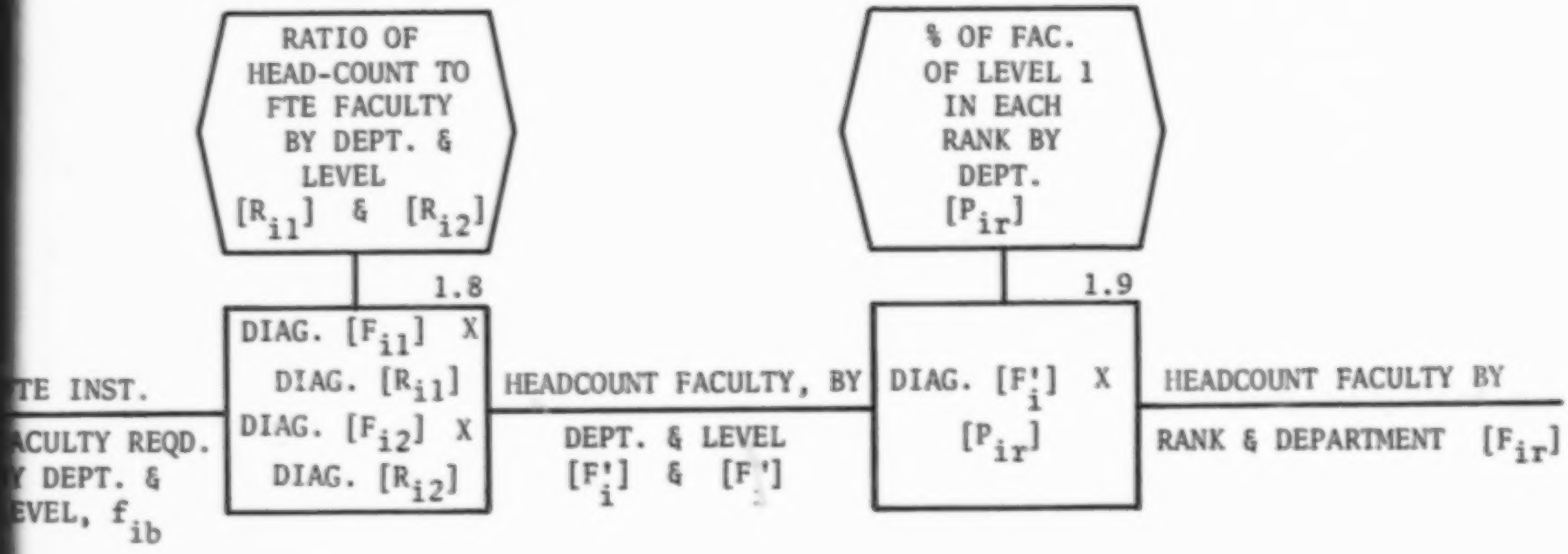
This we cannot determine, however, until the model as a whole begins to function.

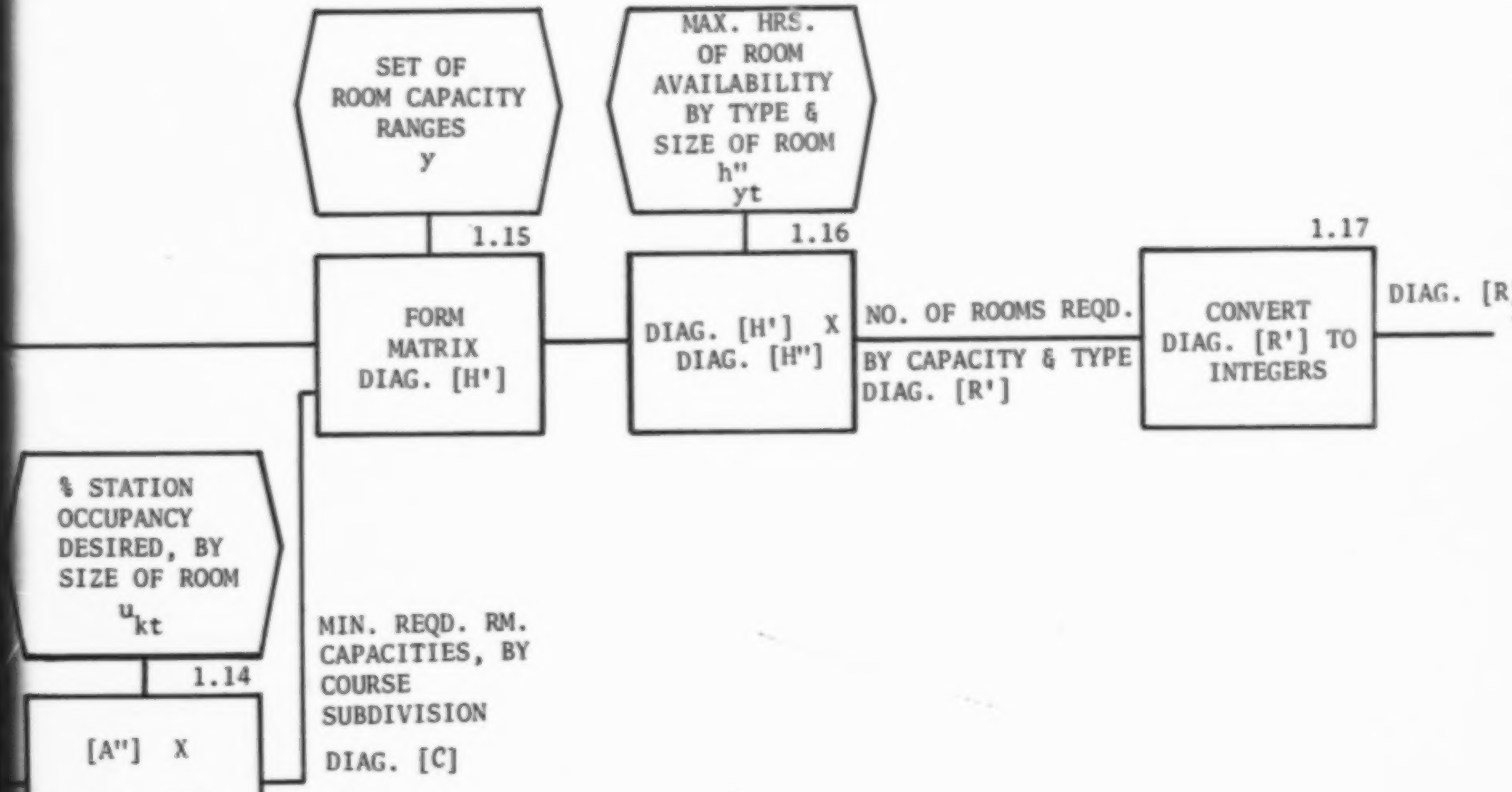
SUBMODEL NO. 1
FTE & HEADCOUNT FACULTY REQUIRED
INSTRUCTIONAL ROOMS REQUIRED, BY CAPACITY & TYPE


% OF STUD. IN EACH LEVEL & PROGRAM TAKING COURSE r_{ijk}
1.1
STUDENT BODY BY PROGRAM & ACADEMIC LEVEL N_{ij}
[R] X [N]
ENROLLMENT IN EACH COURSE [E]
1.2
FORM DIAGONAL MATRIX [E] → [E_1]
[E_1]
MAX. NO. OF STUDENTS/SEC PER COURSE
[M] X [E_1]

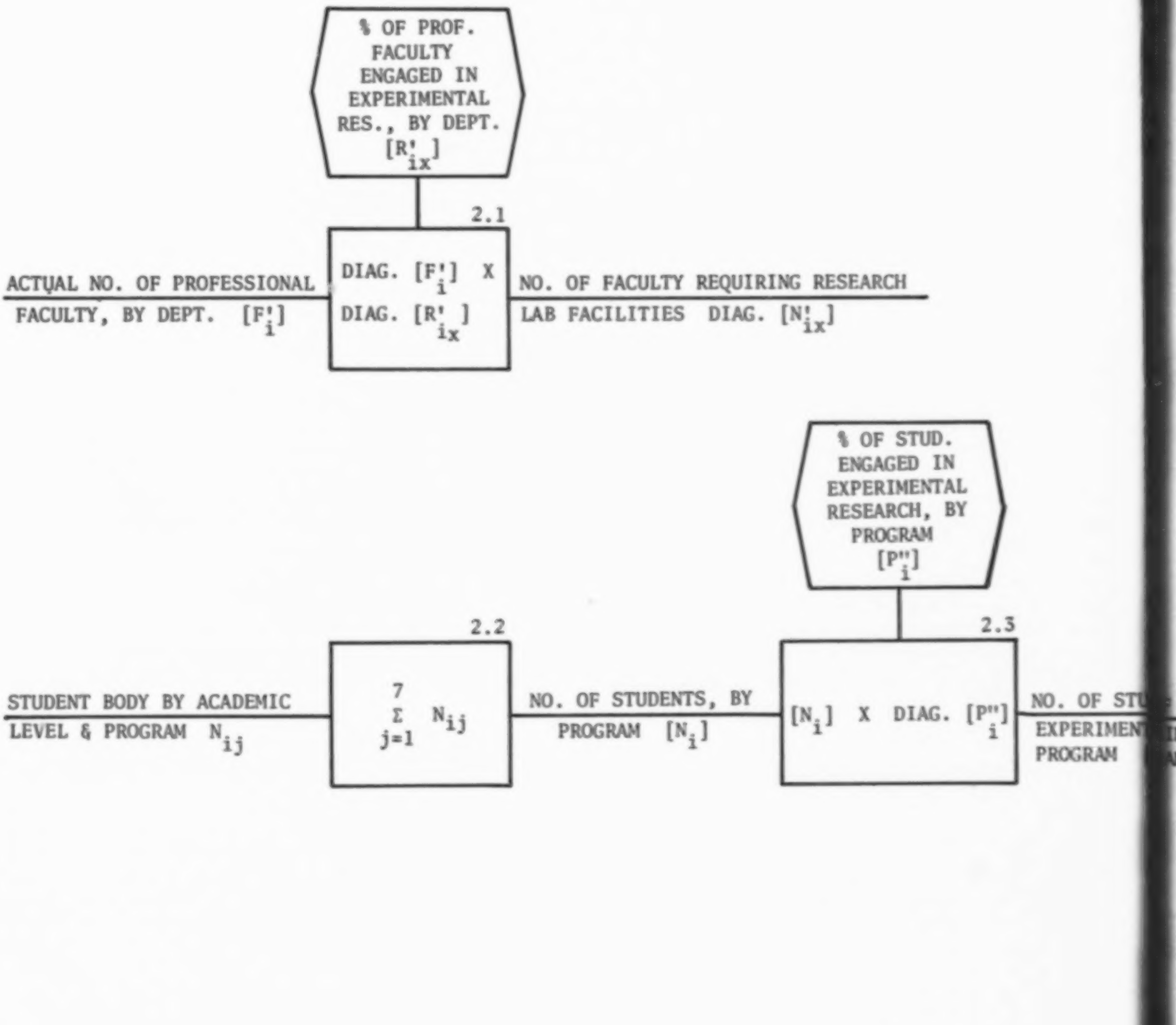

NO. OF
NTS/SEC.
COURSE
IVISION
a_{kt}
1.3
X $[E_1]$
NO. OF SECTIONS
REQUIRED FOR EACH
COURSE SUBDIVISION
[S]
1.4
CHANGE
ELEMENTS OF
[S] TO
INTEGRAL NOS.
[S] → [S']
% FTE INST.
LOAD FOR FAC.
LEVEL 1, BY
COURSE SUB-
DIVISION
$[L_1]$
1.5
$[S']^T$ X $[L_1]$
FTE 1ST LEVEL
INSTRUCTIONAL
FAC. REQUIRED,
BY COURSE
SUBDIVISION $[F_1]$
% FTE INST.
LOAD FOR FAC.
LEVEL 2, BY
COURSE SUB-
DIVISION
$[L_2]$
1.6
$[S']^T$ X $[L_2]$
FTE 2ND LEVEL
INSTRUCTIONAL
FAC. REQUIRED,
BY COURSE
SUBDIVISION $[F_2]$
1
SUM BY
DEPARTMENT
& LEVEL
WEEKLY
CONTACT HRS.
PER SECTION
PER COURSE
SUBDIVISION
c_{kt}
1.10
[C] X $[S'_2]$
CONTACT HOURS BY COURSE
SUBDIVISION [H]
1.11
INVERT MATRIX
ELEMENTS
[S'] → $[S'_1]$
1.12
$[S'_1$ X $[E_1]$
AVE. NO. OF STUDENTS
PER SECTION/COURSE
(INTEGERS) [A] → [A']
1
FORM DIAGON
MATRIX
[A"]

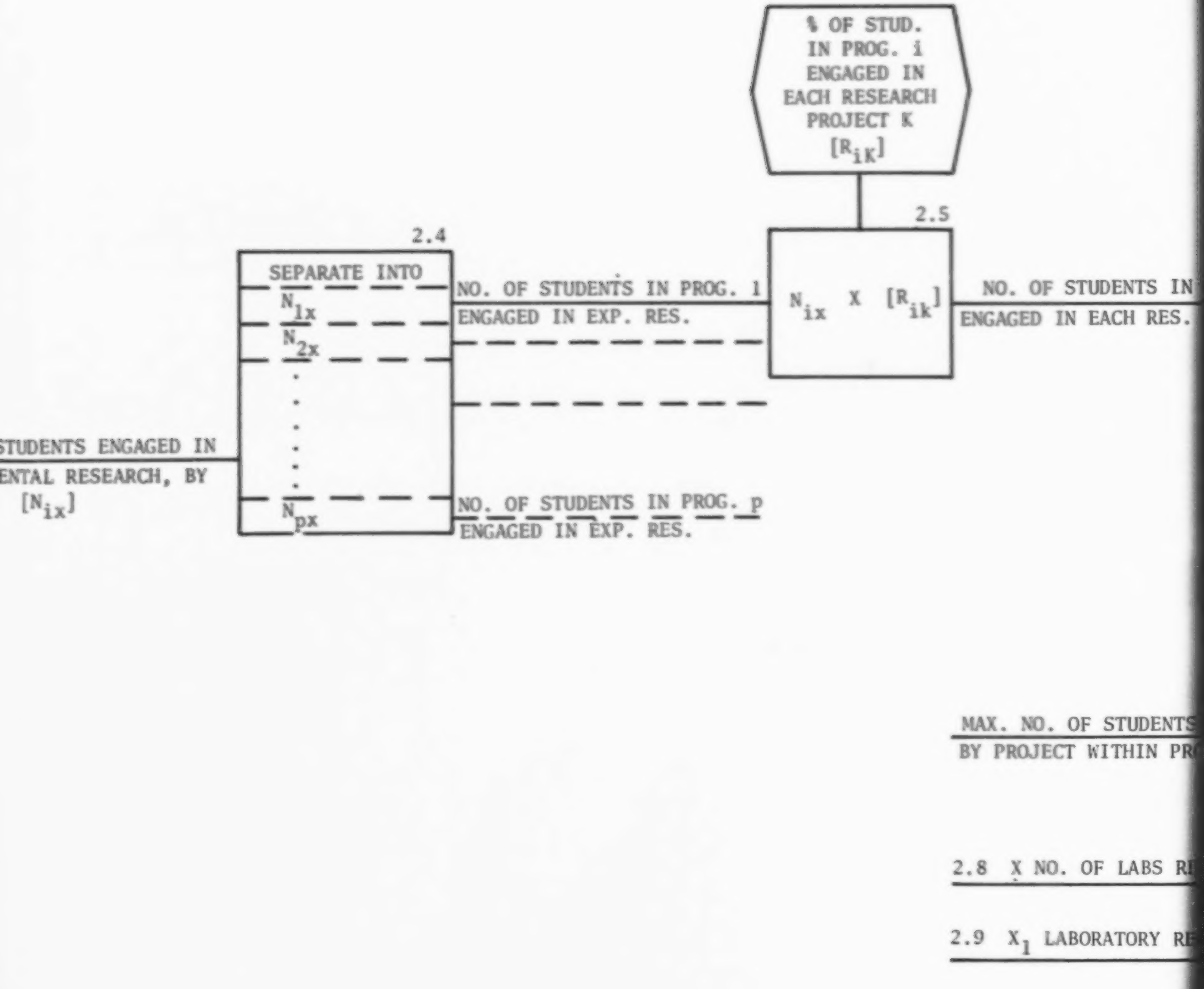

RATIO OF HEAD-COUNT TO FTE FACULTY BY DEPT. & LEVEL [R_i1] & [R_i2]
% OF FAC. OF LEVEL 1 IN EACH RANK BY DEPT. [P_ir]
1]
1.7
SUM BY DEPARTMENT & LEVEL
FTE INST.
FACULTY REQD. BY DEPT. & LEVEL, f_ib
1.8
DIAG. [F_i1] X DIAG. [R_i1]
DIAG. [F_i2] X DIAG. [R_i2]
HEADCOUNT FACULTY, BY
DEPT. & LEVEL [F'_i] & [F"_i]
1.9
DIAG. [F'_i] X [P_ir]
HEADCOUNT F
RANK & DEPAR
[F_2]
SET OF ROOM CAPACITY RANGES y
MAX. HRS. OF ROOM AVAILABILITY BY TYPE & SIZE OF ROOM h"_yt
BY COURSE
H]
1.15
FORM MATRIX DIAG. [H']
1.16
DIAG. [H'] X DIAG. [H"]
NO. OF ROOMS REQD.
BY CAPACITY & TYPE DIAG. [R']
D
% STATION OCCUPANCY DESIRED, BY SIZE OF ROOM u_kt
MIN. REQD. RM. CAPACITIES, BY COURSE SUBDIVISION
DIAG. [C]
1.13
1.14
UDENTS
URSE
] → [A']
FORM DIAGONAL MATRIX [A"]
[A"] X DIAG. [U]

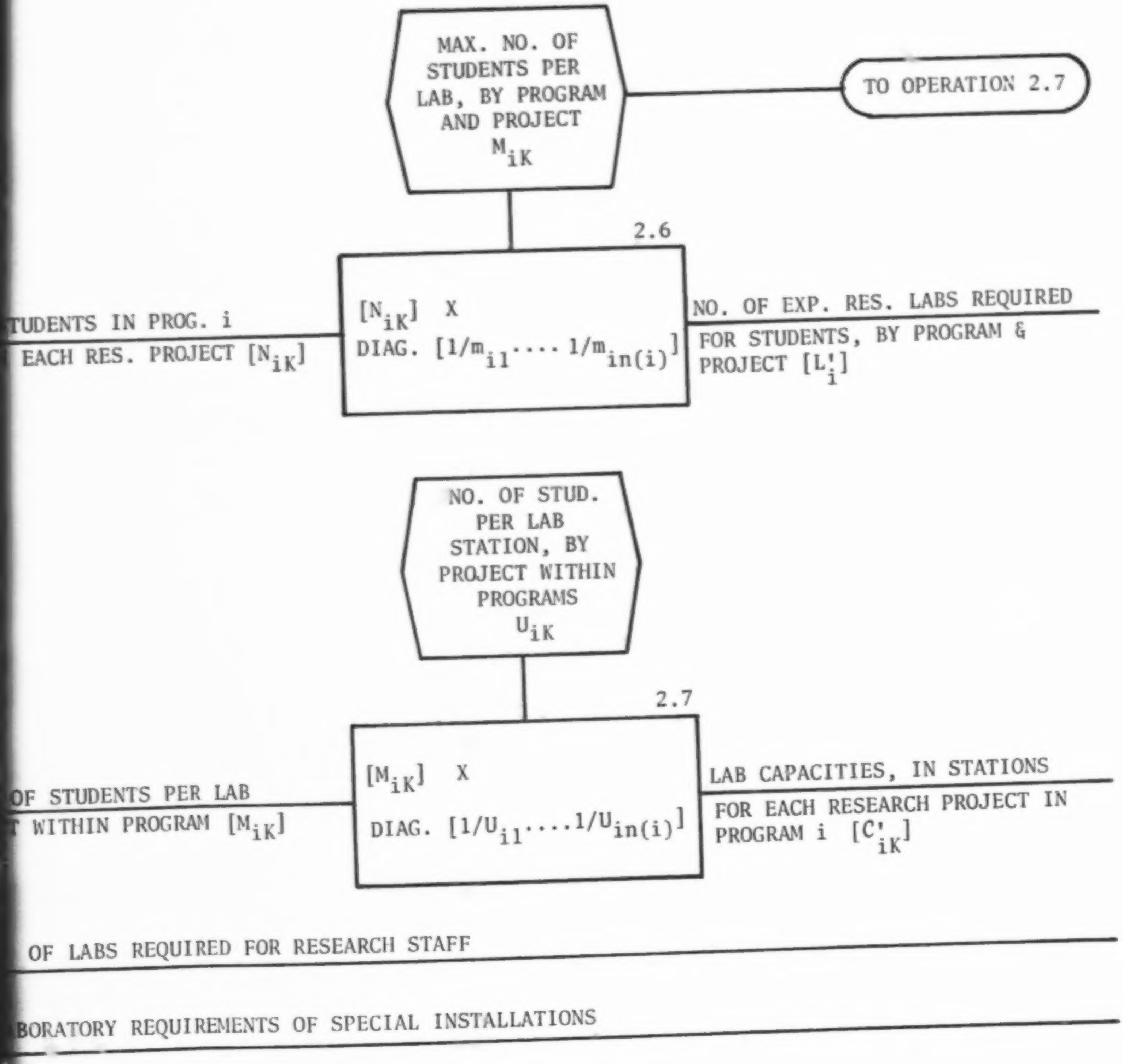

RATIO OF HEAD-COUNT TO FTE FACULTY BY DEPT. & LEVEL $[R_{i1}]$ & $[R_{i2}]$
1.8
DIAG. $[F_{i1}]$ X DIAG. $[R_{i1}]$
DIAG. $[F_{i2}]$ X DIAG. $[R_{i2}]$
TE INST.
ACULTY REQD.
Y DEPT. &
EVEL, f_{ib}
HEADCOUNT FACULTY, BY DEPT. & LEVEL $[F_i']$ & $[F']$
% OF FAC. OF LEVEL 1 IN EACH RANK BY DEPT. $[P_{ir}]$
1.9
DIAG. $[F_i']$ X $[P_{ir}]$
HEADCOUNT FACULTY BY RANK & DEPARTMENT $[F_{ir}]$


SET OF ROOM CAPACITY RANGES y
1.15
FORM MATRIX DIAG. [H']
MAX. HRS. OF ROOM AVAILABILITY BY TYPE & SIZE OF ROOM h''_{yt}
1.16
DIAG. [H'] X DIAG. [H"]
NO. OF ROOMS REQD. BY CAPACITY & TYPE DIAG. [R']
1.17
CONVERT DIAG. [R'] TO INTEGERS
DIAG. $[R_1']$
% STATION OCCUPANCY DESIRED, BY SIZE OF ROOM u_{kt}
1.14
[A"] X DIAG. [U]
MIN. REQD. RM. CAPACITIES, BY COURSE SUBDIVISION DIAG. [C]

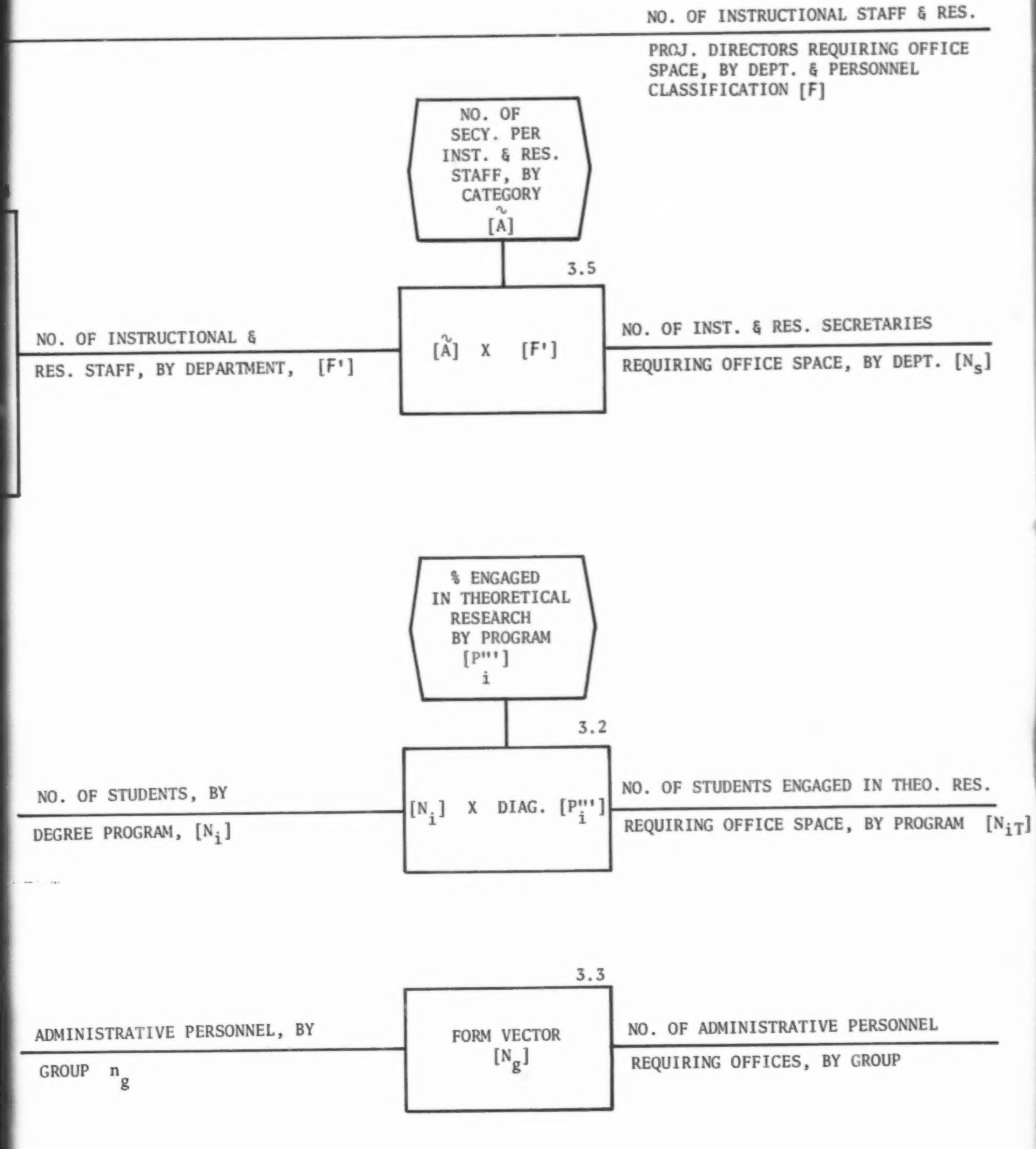
SUBMODEL NO. 2
RESEARCH FACILITIES


% OF PROF. FACULTY ENGAGED IN EXPERIMENTAL RES., BY DEPT. $[R'_{ix}]$
2.1
ACTUAL NO. OF PROFESSIONAL FACULTY, BY DEPT. $[F'_i]$
DIAG. $[F'_i]$ X DIAG. $[R'_{ix}]$
NO. OF FACULTY REQUIRING RESEARCH LAB FACILITIES DIAG. $[N'_{ix}]$
% OF STUD. ENGAGED IN EXPERIMENTAL RESEARCH, BY PROGRAM $[P''_i]$
2.2
STUDENT BODY BY ACADEMIC LEVEL & PROGRAM N_{ij}
$\sum_{j=1}^{7} N_{ij}$
NO. OF STUDENTS, BY PROGRAM $[N_i]$
2.3
$[N_i]$ X DIAG. $[P''_i]$
NO. OF STU
EXPERIMEN
PROGRAM

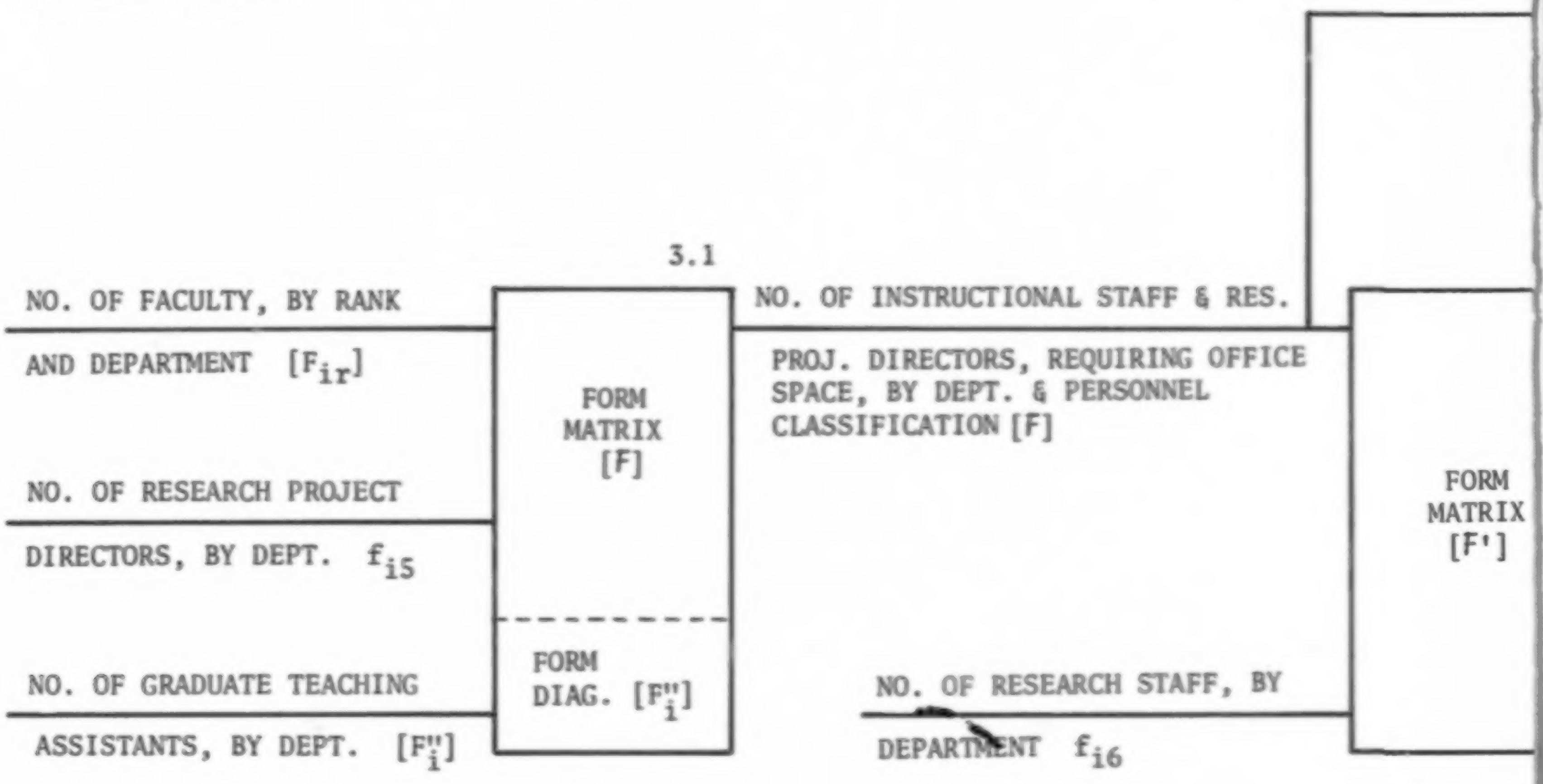

% OF STUD.
IN PROG. i
ENGAGED IN
EACH RESEARCH
PROJECT K
[R_{iK}]
2.4
SEPARATE INTO
N_{1x}
N_{2x}
N_{px}
2.5
N_{ix} X [R_{ik}]
NO. OF STUDENTS IN PROG. 1
ENGAGED IN EXP. RES.
NO. OF STUDENTS IN PROG. p
ENGAGED IN EXP. RES.
NO. OF STUDENTS IN
ENGAGED IN EACH RES.
STUDENTS ENGAGED IN
ENTAL RESEARCH, BY
[N_{ix}]
MAX. NO. OF STUDENTS
BY PROJECT WITHIN PR
2.8 X NO. OF LABS R
2.9 X_1 LABORATORY R



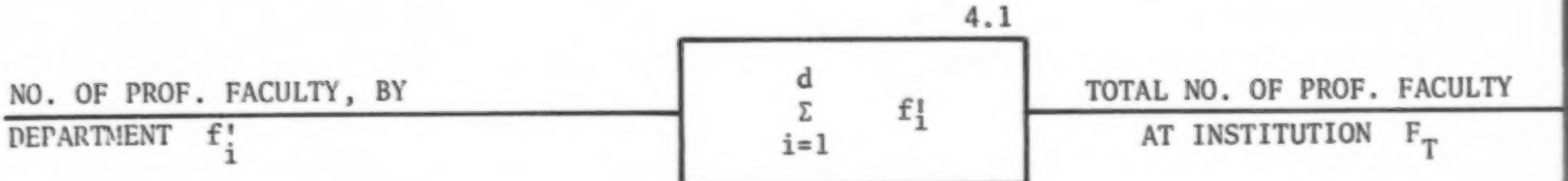
MAX. NO. OF STUDENTS PER LAB, BY PROGRAM AND PROJECT M_{iK}
TO OPERATION 2.7
2.6
TUDENTS IN PROG. i
EACH RES. PROJECT $[N_{iK}]$
$[N_{iK}]$ X DIAG. $[1/m_{i1} \cdots 1/m_{in(i)}]$
NO. OF EXP. RES. LABS REQUIRED FOR STUDENTS, BY PROGRAM & PROJECT $[L'_i]$
NO. OF STUD. PER LAB STATION, BY PROJECT WITHIN PROGRAMS U_{iK}
2.7
OF STUDENTS PER LAB
T WITHIN PROGRAM $[M_{iK}]$
$[M_{iK}]$ X DIAG. $[1/U_{i1} \cdots 1/U_{in(i)}]$
LAB CAPACITIES, IN STATIONS FOR EACH RESEARCH PROJECT IN PROGRAM i $[C'_{iK}]$
OF LABS REQUIRED FOR RESEARCH STAFF
BORATORY REQUIREMENTS OF SPECIAL INSTALLATIONS

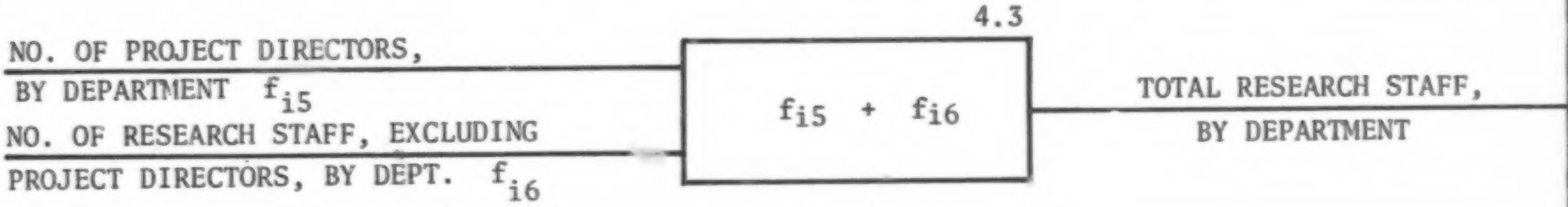

NO. OF INSTRUCTIONAL STAFF & RES.
PROJ. DIRECTORS REQUIRING OFFICE SPACE, BY DEPT. & PERSONNEL CLASSIFICATION [F]
NO. OF SECY. PER INST. & RES. STAFF, BY CATEGORY $[\tilde{A}]$
3.5
NO. OF INSTRUCTIONAL & RES. STAFF, BY DEPARTMENT, [F']
$[\tilde{A}]$ X [F']
NO. OF INST. & RES. SECRETARIES REQUIRING OFFICE SPACE, BY DEPT. $[N_s]$
% ENGAGED IN THEORETICAL RESEARCH BY PROGRAM $[P'''_i]$
3.2
NO. OF STUDENTS, BY DEGREE PROGRAM, $[N_i]$
$[N_i]$ X DIAG. $[P'''_i]$
NO. OF STUDENTS ENGAGED IN THEO. RES. REQUIRING OFFICE SPACE, BY PROGRAM $[N_{iT}]$
3.3
ADMINISTRATIVE PERSONNEL, BY GROUP n_g
FORM VECTOR $[N_g]$
NO. OF ADMINISTRATIVE PERSONNEL REQUIRING OFFICES, BY GROUP

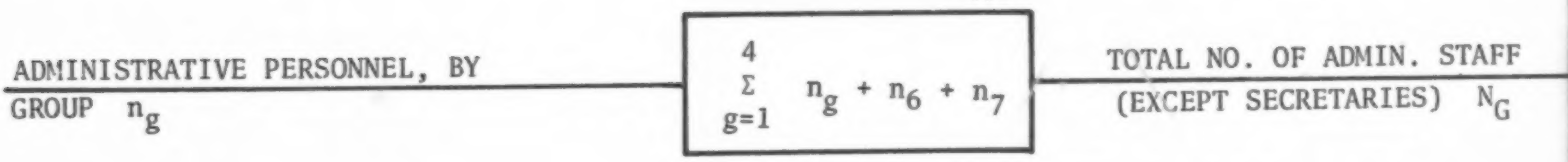
SUBMODEL NO. 3
OFFICE FACILITIES

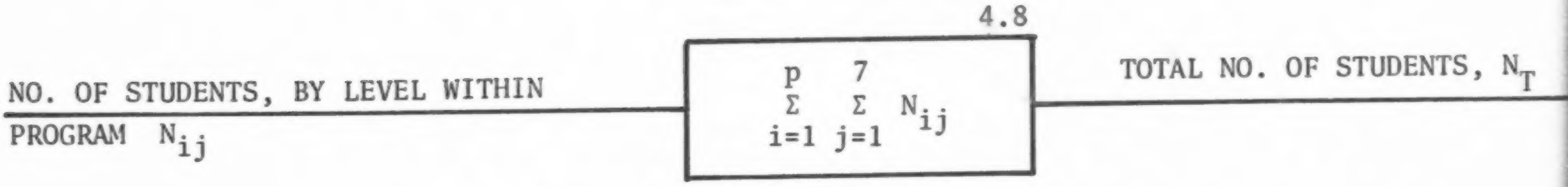

3.1
NO. OF FACULTY, BY RANK AND DEPARTMENT [F_{ir}]
NO. OF RESEARCH PROJECT DIRECTORS, BY DEPT. f_{i5}
NO. OF GRADUATE TEACHING ASSISTANTS, BY DEPT. [F_i'']
FORM MATRIX [F]
FORM DIAG. [F_i'']
NO. OF INSTRUCTIONAL STAFF & RES. PROJ. DIRECTORS, REQUIRING OFFICE SPACE, BY DEPT. & PERSONNEL CLASSIFICATION [F]
NO. OF RESEARCH STAFF, BY DEPARTMENT f_{i6}
FORM MATRIX [F']

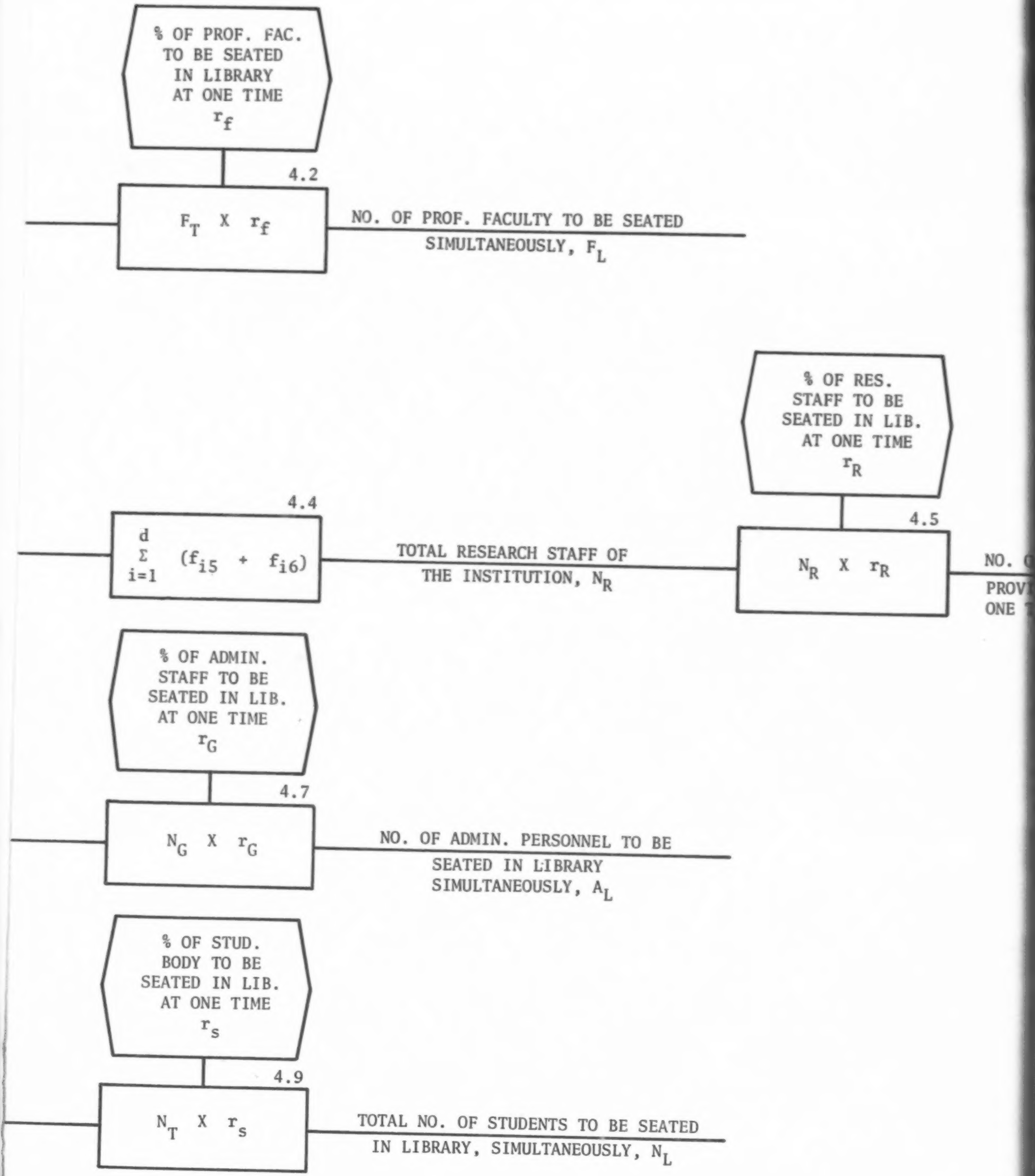
SUBMODEL NO. 4
LIBRARY - USER FACILITIES

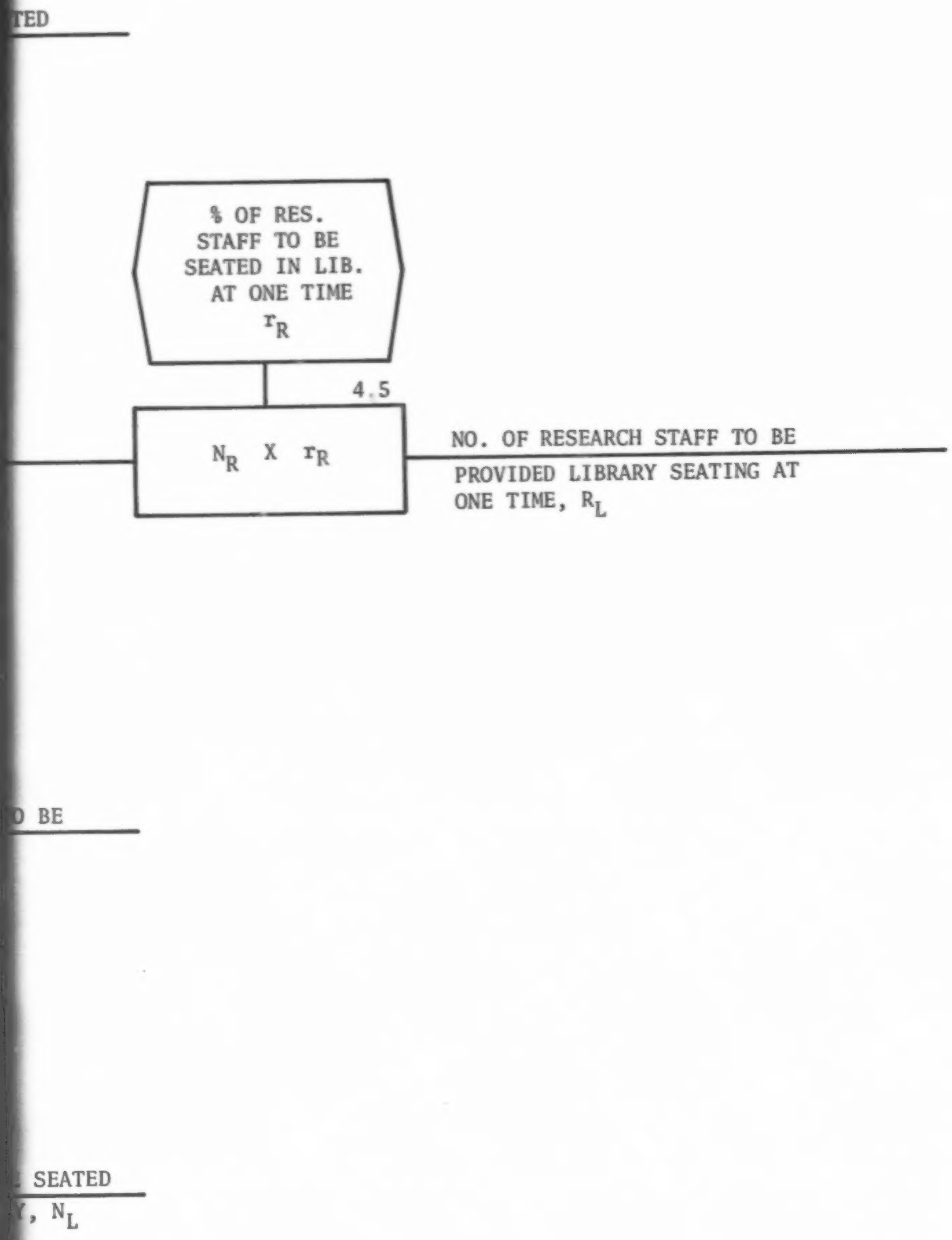

4.1
NO. OF PROF. FACULTY, BY DEPARTMENT f_i'
$\sum_{i=1}^{d} f_i'$
TOTAL NO. OF PROF. FACULTY AT INSTITUTION F_T


4.3
NO. OF PROJECT DIRECTORS, BY DEPARTMENT f_{i5}
NO. OF RESEARCH STAFF, EXCLUDING PROJECT DIRECTORS, BY DEPT. f_{i6}
$f_{i5} + f_{i6}$
TOTAL RESEARCH STAFF, BY DEPARTMENT


4.6
ADMINISTRATIVE PERSONNEL, BY GROUP n_g
$\sum_{g=1}^{4} n_g + n_6 + n_7$
TOTAL NO. OF ADMIN. STAFF (EXCEPT SECRETARIES) N_G


4.8
NO. OF STUDENTS, BY LEVEL WITHIN PROGRAM N_{ij}
$\sum_{i=1}^{p} \sum_{j=1}^{7} N_{ij}$
TOTAL NO. OF STUDENTS, N_T


% OF PROF. FAC. TO BE SEATED IN LIBRARY AT ONE TIME r_f
4.2
F_T X r_f
NO. OF PROF. FACULTY TO BE SEATED SIMULTANEOUSLY, F_L
% OF RES. STAFF TO BE SEATED IN LIB. AT ONE TIME r_R
4.4
$\sum_{i=1}^{d} (f_{i5} + f_{i6})$
TOTAL RESEARCH STAFF OF THE INSTITUTION, N_R
4.5
N_R X r_R
NO.
PROV
ONE
% OF ADMIN. STAFF TO BE SEATED IN LIB. AT ONE TIME r_G
4.7
N_G X r_G
NO. OF ADMIN. PERSONNEL TO BE SEATED IN LIBRARY SIMULTANEOUSLY, A_L
% OF STUD. BODY TO BE SEATED IN LIB. AT ONE TIME r_s
4.9
N_T X r_s
TOTAL NO. OF STUDENTS TO BE SEATED IN LIBRARY, SIMULTANEOUSLY, N_L


TED
% OF RES. STAFF TO BE SEATED IN LIB. AT ONE TIME r_R
4.5
N_R X r_R
NO. OF RESEARCH STAFF TO BE PROVIDED LIBRARY SEATING AT ONE TIME, R_L
O BE
SEATED
Y, N_L

SUBMODEL NO. 4
LIBRARY - ACTIVE STORAGE FACILITIES

N
RE
UN
INPUT
v_p,

MIN. NO. OF BOOKS REQUIRED TO ESTABLISH EACH DEGREE PROGRAM, b_p

TOTAL NO. OF STUDENTS IN DEGREE PROGRAM, N_p

NO. OF UNDERGRADS IN HONORS PROGRAMS, BY PROGRAM, H_p

NO. OF STUDENTS ENROLLED FOR MASTERS DEGREES, BY PROGRAM, M_p

NO. OF STUDENTS ENROLLED FOR DOCTORS DEGREES, BY PROGRAM, D_p

NO. OF FACULTY & RESEARCH STAFF, BY DEPARTMENT, F''_1

NO. OF ADMIN. PERSONNEL (EXCEPT SECRETARIES), N_a

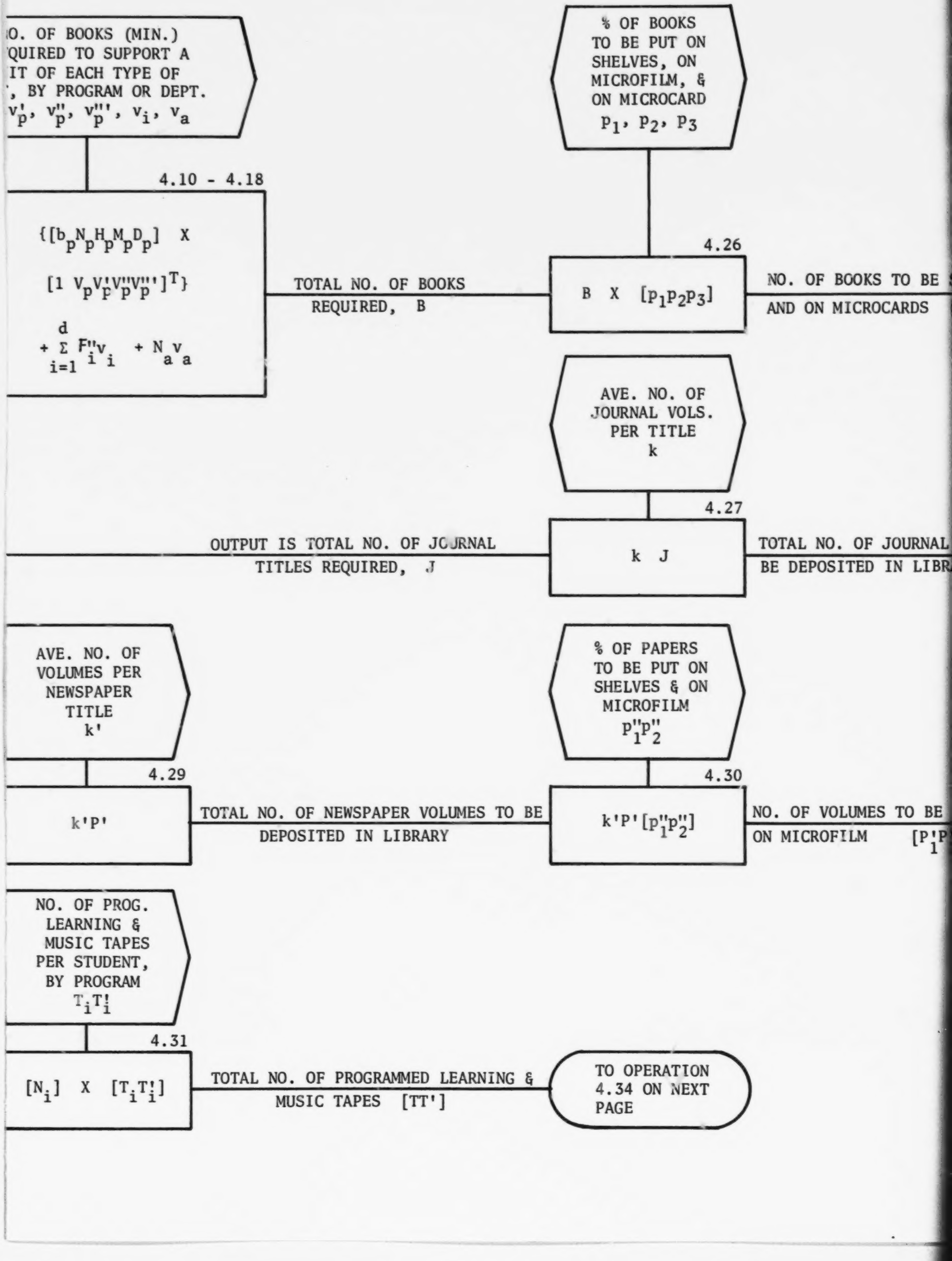
$\sum_{p=1}^{p}$

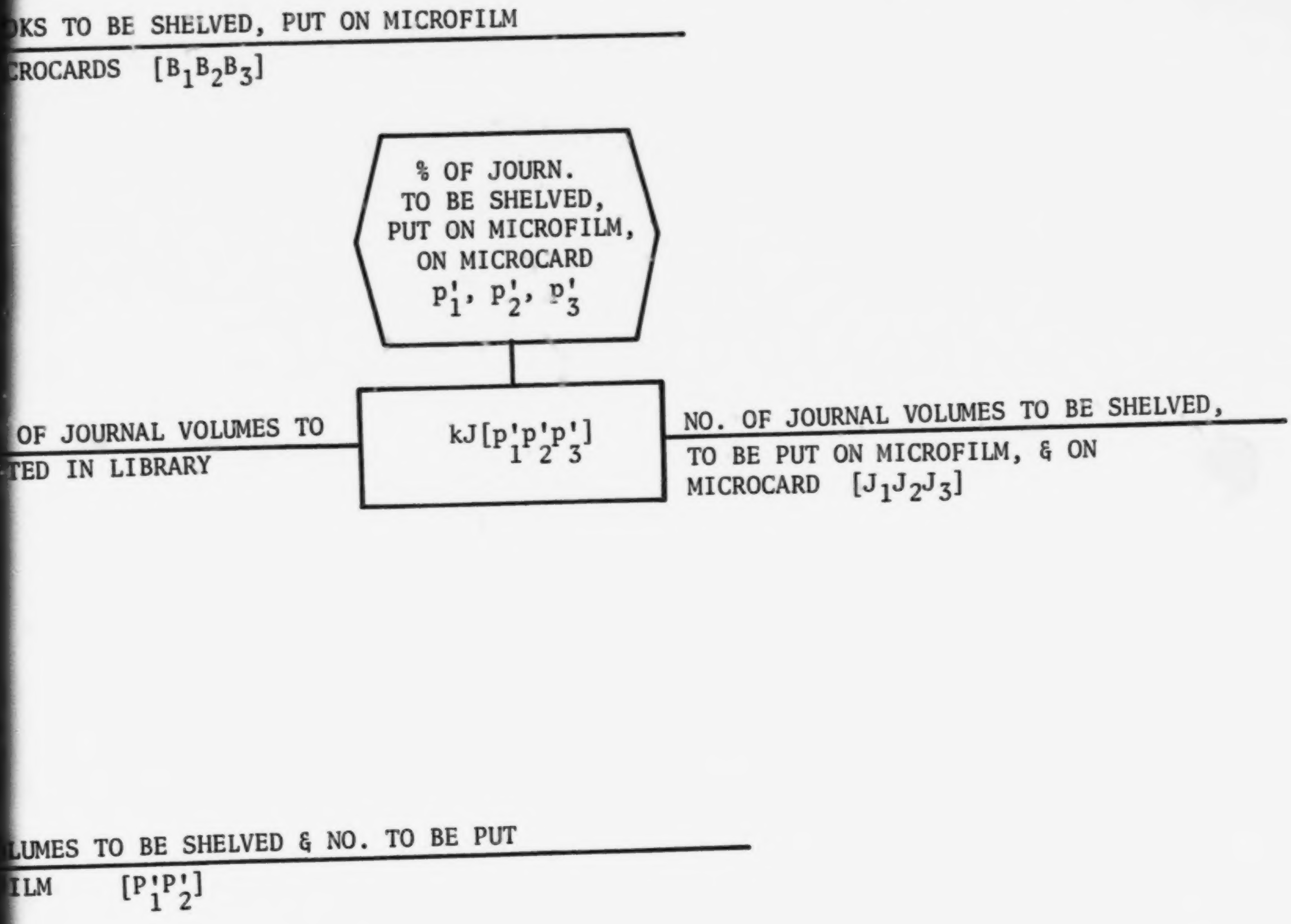
THE INPUTS TO OPERATIONS 4.19 - 4.25 ARE THE SAME AS INPUTS TO OPERATIONS 4.10 - 4.18

DECISION PARAMETERS ARE MIN. NO. OF JOURNALS REQUIRED TO SUPPORT A UNIT OF EACH TYPE OF INPUT, BY PROGRAM OR DEPT. [1 $V_p V'_p V''_p V'''_p V_1 V_a$]

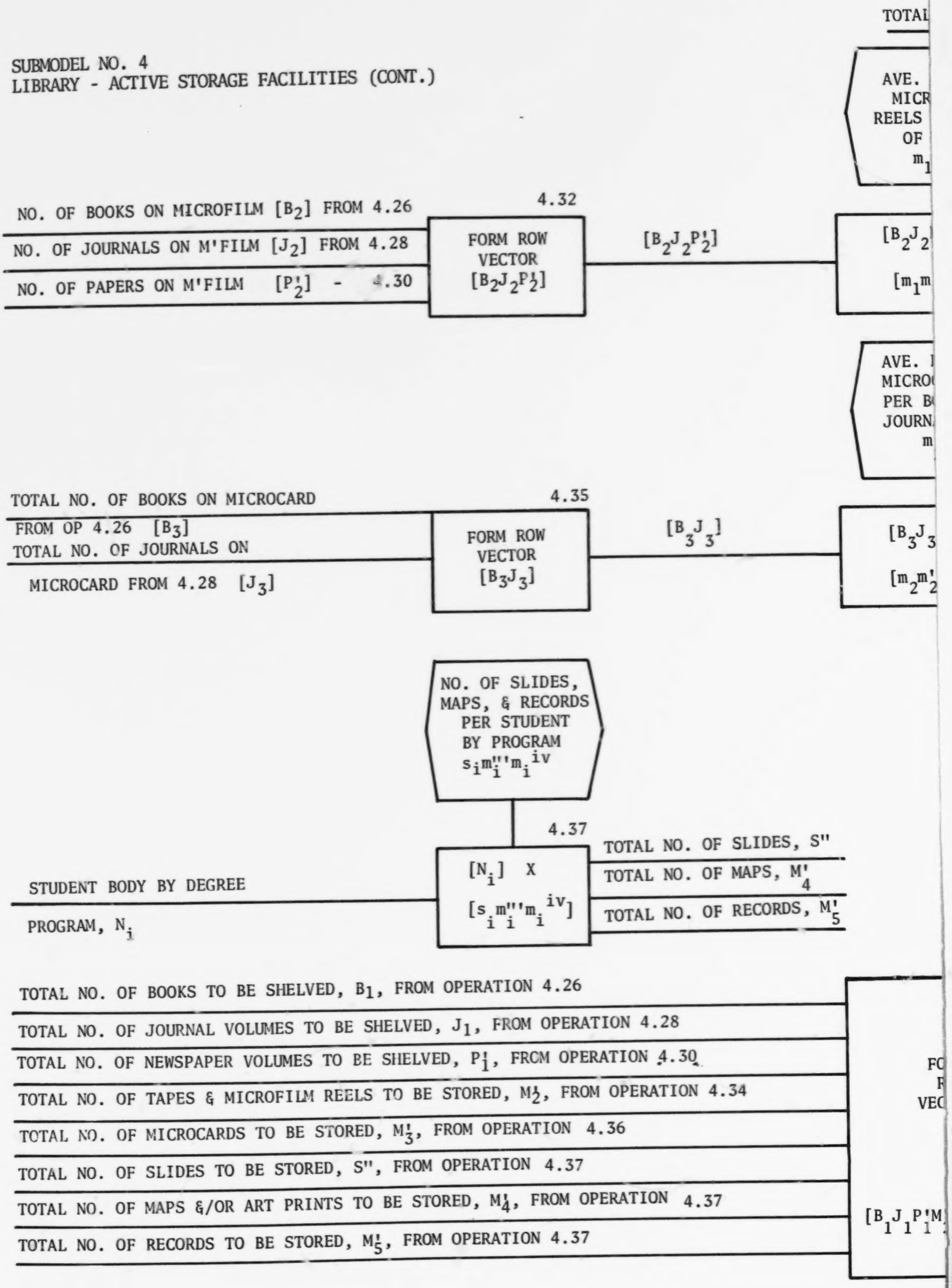
NO. OF NEWSPAPER TITLES OBTAINED FOR LIBRARY USE, P'

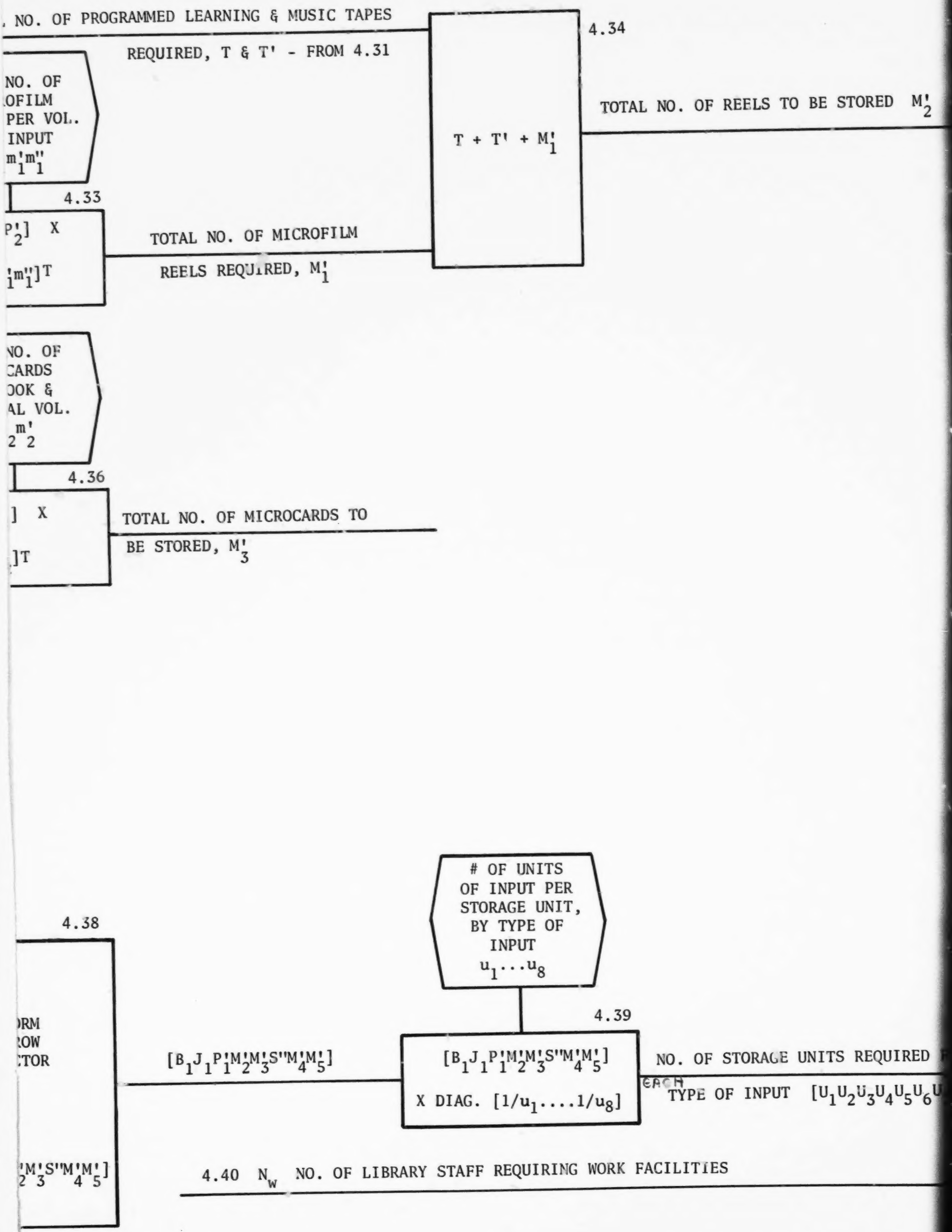
STUDENT ENROLLMENT BY DEGREE PROGRAM, $[N_i]$


O. OF BOOKS (MIN.)
QUIRED TO SUPPORT A
IT OF EACH TYPE OF
, BY PROGRAM OR DEPT.
$v_p', v_p'', v_p''', v_i, v_a$
4.10 - 4.18
$\{[b_p N_p H_p M_p D_p] \times [1\ V_p V_p' V_p'' V_p''']^T\} + \sum_{i=1}^{d} F_i'' v_i + N_a v_a$
TOTAL NO. OF BOOKS REQUIRED, B
% OF BOOKS TO BE PUT ON SHELVES, ON MICROFILM, & ON MICROCARD
p_1, p_2, p_3
4.26
$B \times [p_1 p_2 p_3]$
NO. OF BOOKS TO BE
AND ON MICROCARDS
AVE. NO. OF JOURNAL VOLS. PER TITLE
k
4.27
k J
OUTPUT IS TOTAL NO. OF JOURNAL TITLES REQUIRED, J
TOTAL NO. OF JOURNAL
BE DEPOSITED IN LIBR
AVE. NO. OF VOLUMES PER NEWSPAPER TITLE
k'
4.29
k'P'
TOTAL NO. OF NEWSPAPER VOLUMES TO BE DEPOSITED IN LIBRARY
% OF PAPERS TO BE PUT ON SHELVES & ON MICROFILM
$p_1'' p_2''$
4.30
$k'P'[p_1'' p_2'']$
NO. OF VOLUMES TO BE
ON MICROFILM
$[P_1' P$
NO. OF PROG. LEARNING & MUSIC TAPES PER STUDENT, BY PROGRAM
$T_i T_i'$
4.31
$[N_i] \times [T_i T_i']$
TOTAL NO. OF PROGRAMMED LEARNING & MUSIC TAPES [TT']
TO OPERATION 4.34 ON NEXT PAGE


OKS TO BE SHELVED, PUT ON MICROFILM
CROCARDS $[B_1B_2B_3]$
% OF JOURN. TO BE SHELVED, PUT ON MICROFILM, ON MICROCARD p'_1, p'_2, p'_3
OF JOURNAL VOLUMES TO
TED IN LIBRARY
$kJ[p'_1p'_2p'_3]$
NO. OF JOURNAL VOLUMES TO BE SHELVED, TO BE PUT ON MICROFILM, & ON MICROCARD $[J_1J_2J_3]$
LUMES TO BE SHELVED & NO. TO BE PUT
ILM $[P'_1P'_2]$

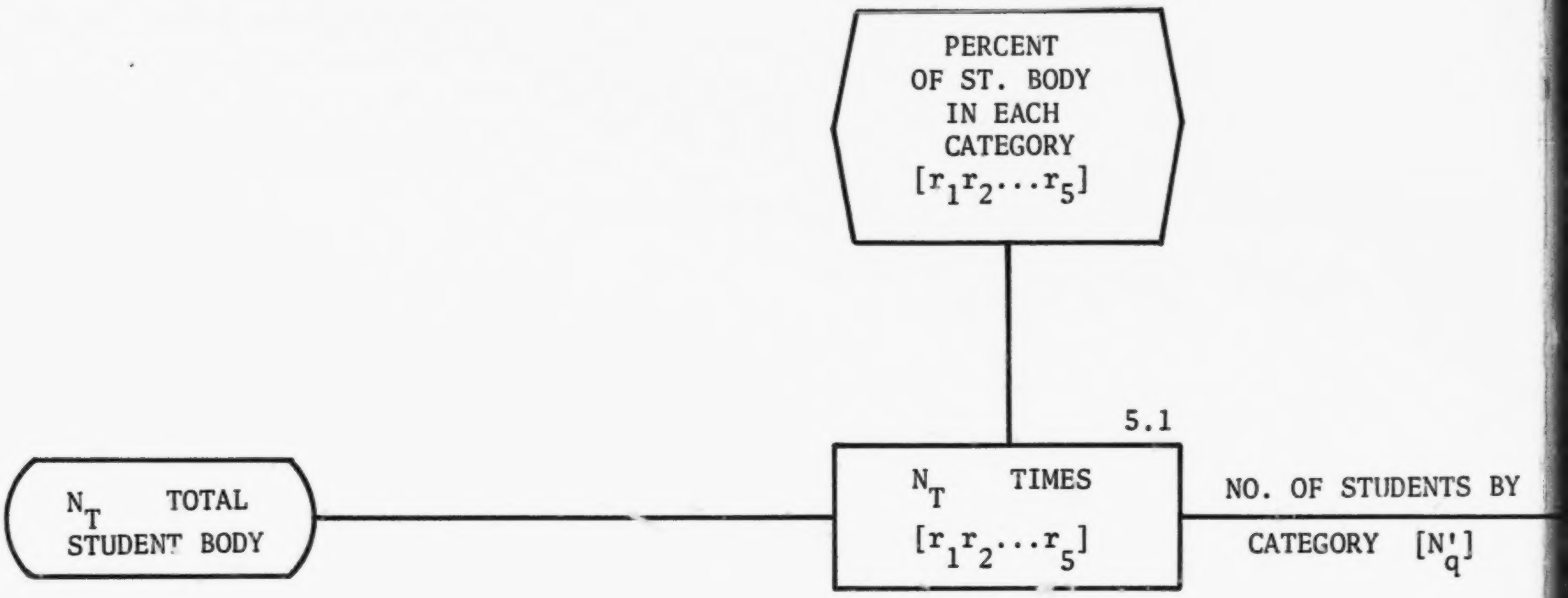
SUBMODEL NO. 4
LIBRARY - ACTIVE STORAGE FACILITIES (CONT.)

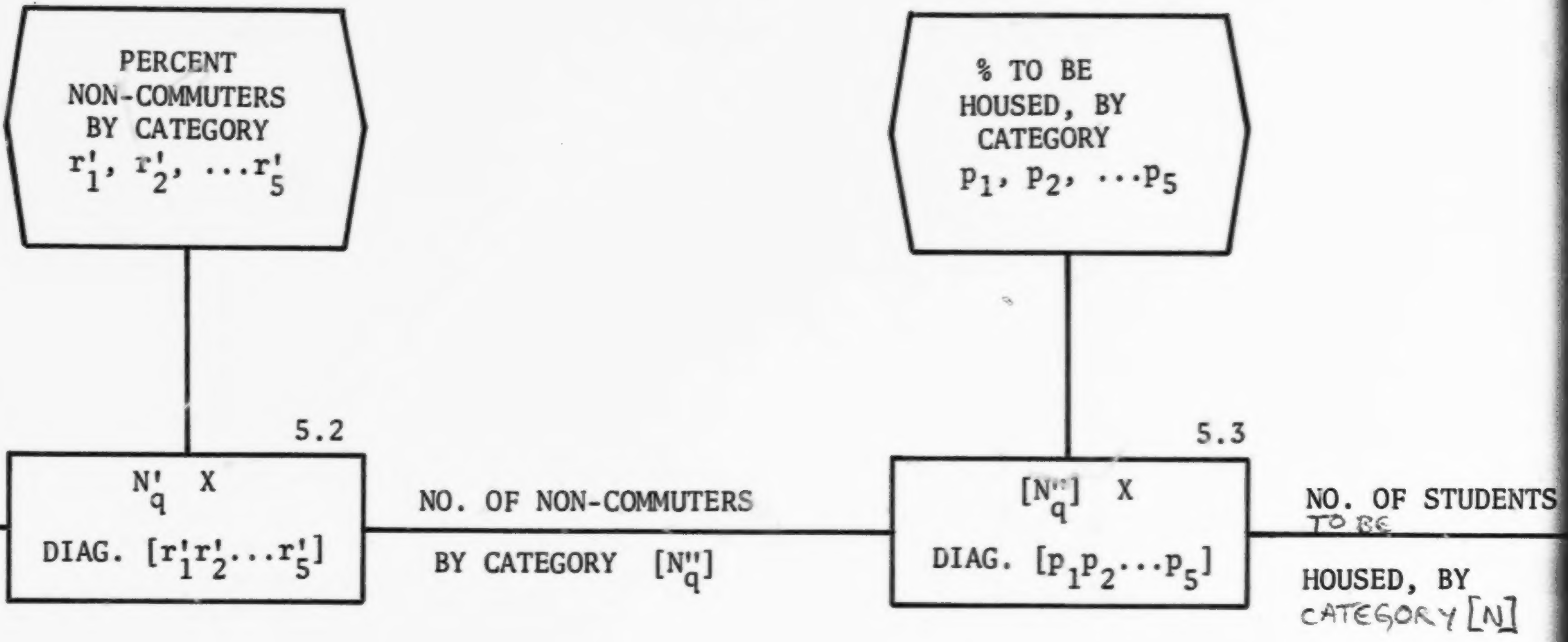

TOTAL
AVE.
MICR
REELS
OF
m_1
NO. OF BOOKS ON MICROFILM [B_2] FROM 4.26
NO. OF JOURNALS ON M'FILM [J_2] FROM 4.28
NO. OF PAPERS ON M'FILM [P'_2] - 4.30
4.32
FORM ROW VECTOR [$B_2J_2P'_2$]
[$B_2J_2P'_2$]
[B_2J_2
[m_1m
AVE.
MICRO
PER B
JOURN
m
TOTAL NO. OF BOOKS ON MICROCARD FROM OP 4.26 [B_3]
TOTAL NO. OF JOURNALS ON MICROCARD FROM 4.28 [J_3]
4.35
FORM ROW VECTOR [B_3J_3]
[B_3J_3]
[B_3J_3
[$m_2m'_2$
NO. OF SLIDES, MAPS, & RECORDS PER STUDENT BY PROGRAM $s_i m'''_i m_i^{iv}$
4.37
STUDENT BODY BY DEGREE PROGRAM, N_i
[N_i] X [$s_i m'''_i m_i^{iv}$]
TOTAL NO. OF SLIDES, S"
TOTAL NO. OF MAPS, M'_4
TOTAL NO. OF RECORDS, M'_5
TOTAL NO. OF BOOKS TO BE SHELVED, B_1, FROM OPERATION 4.26
TOTAL NO. OF JOURNAL VOLUMES TO BE SHELVED, J_1, FROM OPERATION 4.28
TOTAL NO. OF NEWSPAPER VOLUMES TO BE SHELVED, P'_1, FROM OPERATION 4.30
TOTAL NO. OF TAPES & MICROFILM REELS TO BE STORED, M'_2, FROM OPERATION 4.34
TOTAL NO. OF MICROCARDS TO BE STORED, M'_3, FROM OPERATION 4.36
TOTAL NO. OF SLIDES TO BE STORED, S", FROM OPERATION 4.37
TOTAL NO. OF MAPS &/OR ART PRINTS TO BE STORED, M'_4, FROM OPERATION 4.37
TOTAL NO. OF RECORDS TO BE STORED, M'_5, FROM OPERATION 4.37
FO
R
VEC
[$B_1J_1P'_1M$



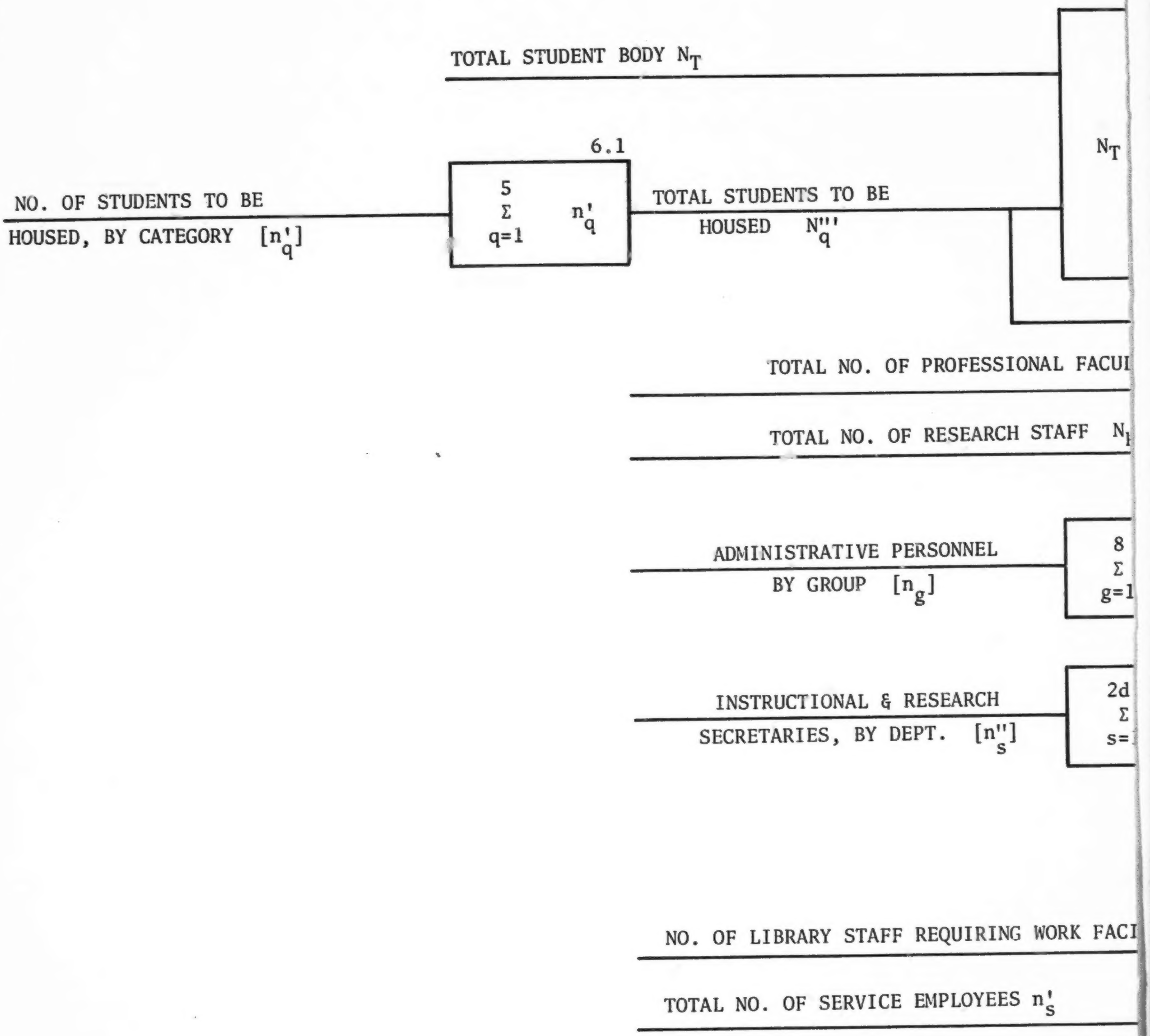
. NO. OF PROGRAMMED LEARNING & MUSIC TAPES
REQUIRED, T & T' - FROM 4.31
4.34
NO. OF
OFILM
PER VOL.
INPUT
$m_1' m_1''$
$T + T' + M_1'$
TOTAL NO. OF REELS TO BE STORED M_2'
4.33
$P_2']$ X
$_1 m_1'']T$
TOTAL NO. OF MICROFILM
REELS REQUIRED, M_1'
NO. OF
CARDS
OOK &
AL VOL.
m_2'
2 2
4.36
] X
]T
TOTAL NO. OF MICROCARDS TO
BE STORED, M_3'
# OF UNITS
OF INPUT PER
STORAGE UNIT,
BY TYPE OF
INPUT
$u_1 \dots u_8$
4.38
ORM
ROW
CTOR
$M_2' M_3' S'' M_4' M_5']$
$[B_1 J_1 P_1' M_2' M_3' S'' M_4' M_5']$
4.39
$[B_1 J_1 P_1' M_2' M_3' S'' M_4' M_5']$
X DIAG. $[1/u_1 \dots 1/u_8]$
NO. OF STORAGE UNITS REQUIRED F
EACH
TYPE OF INPUT $[U_1 U_2 U_3 U_4 U_5 U_6 U$
4.40 N_w NO. OF LIBRARY STAFF REQUIRING WORK FACILITIES

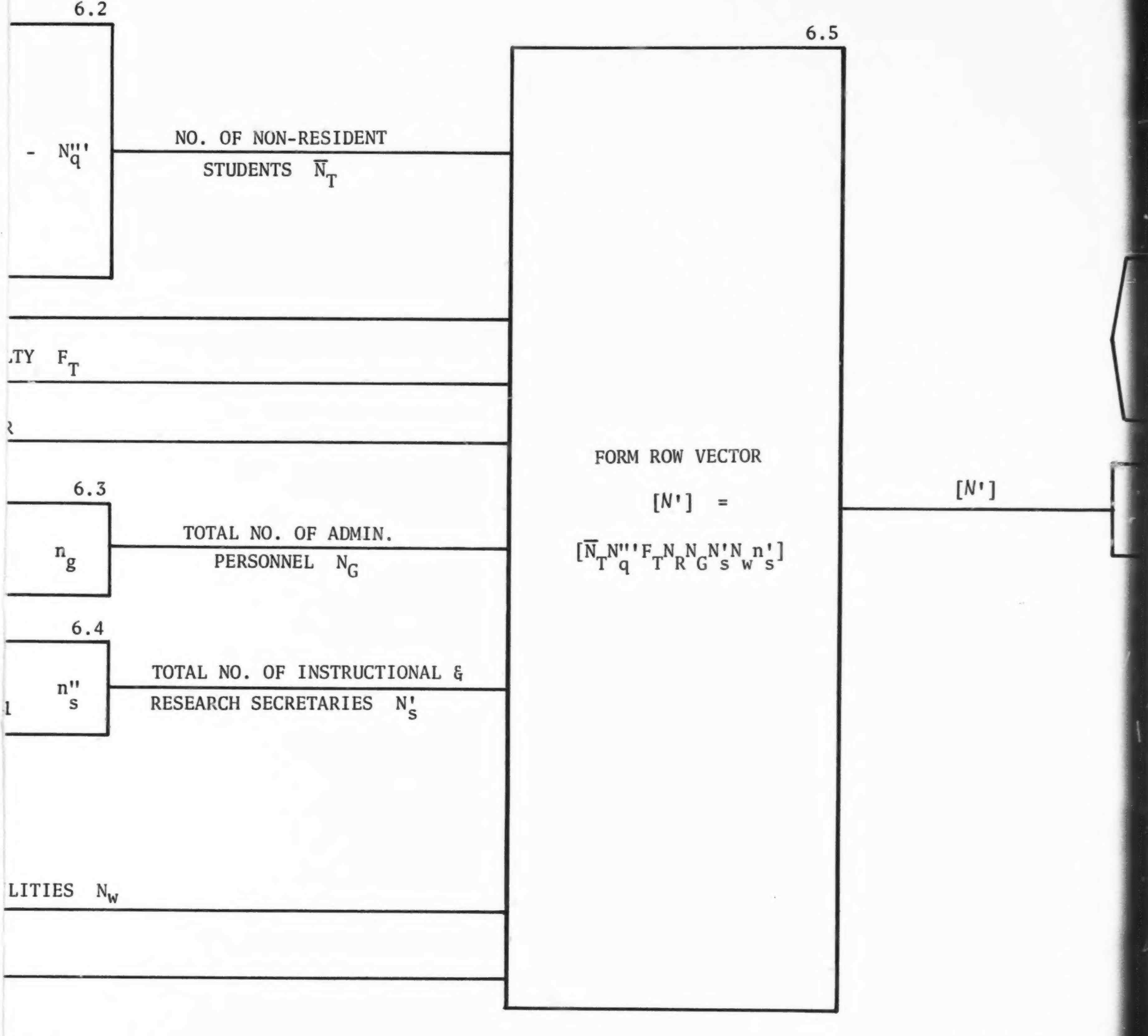
SUBMODEL NO. 5
STUDENT LIVING FACILITIES

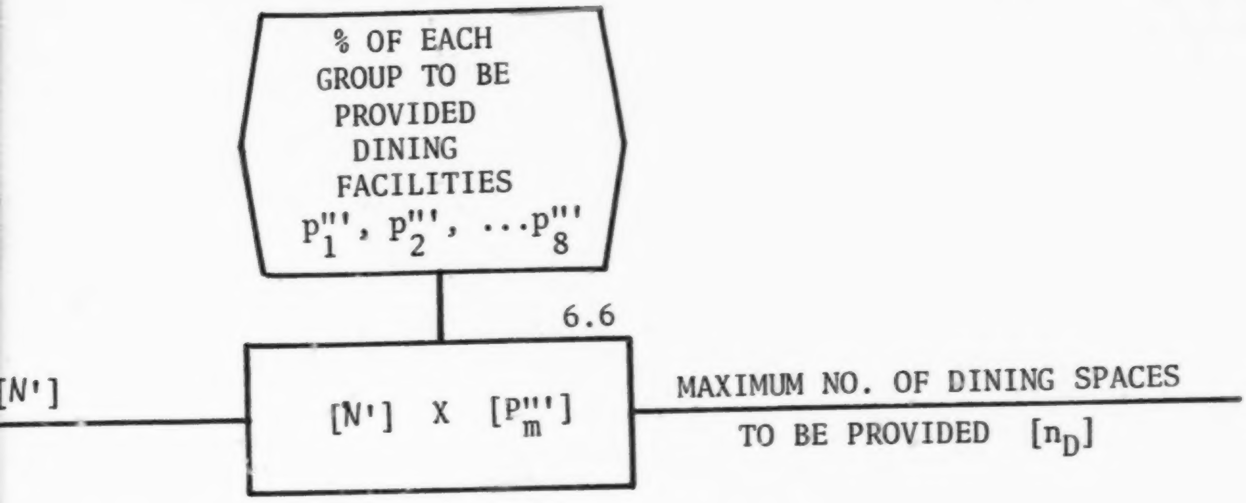

PERCENT OF ST. BODY IN EACH CATEGORY $[r_1 r_2 \ldots r_5]$
5.1
N_T TIMES $[r_1 r_2 \ldots r_5]$
N_T TOTAL STUDENT BODY
NO. OF STUDENTS BY CATEGORY $[N'_q]$


PERCENT NON-COMMUTERS BY CATEGORY
$r'_1, r'_2, \ldots r'_5$
5.2
N'_q X
DIAG. $[r'_1 r'_2 \ldots r'_5]$
NO. OF NON-COMMUTERS BY CATEGORY $[N''_q]$
% TO BE HOUSED, BY CATEGORY
$p_1, p_2, \cdots p_5$
5.3
$[N''_q]$ X
DIAG. $[p_1 p_2 \cdots p_5]$
NO. OF STUDENTS TO BE HOUSED, BY CATEGORY $[N]$

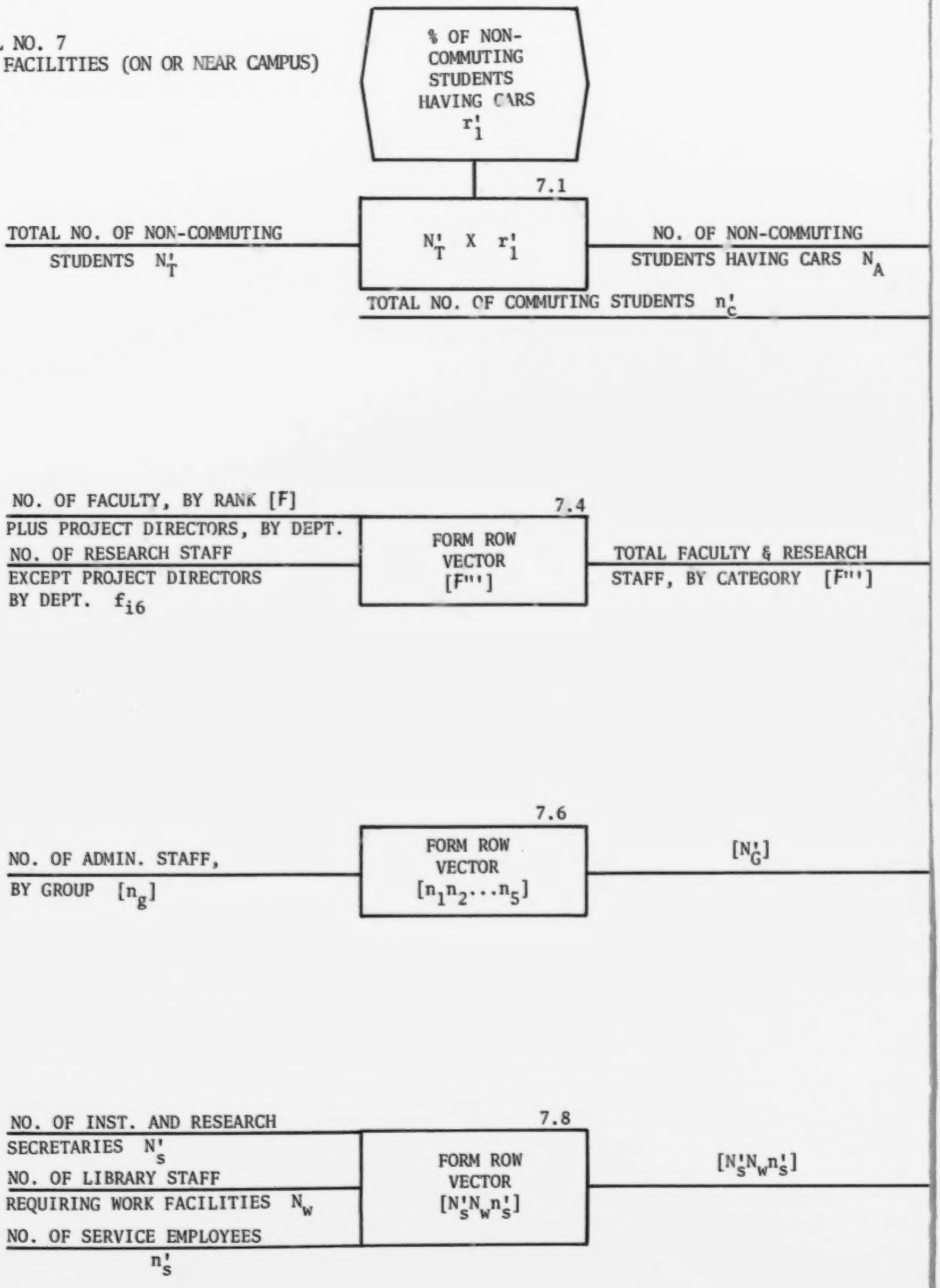
SUBMODEL NO. 6
DINING FACILITIES

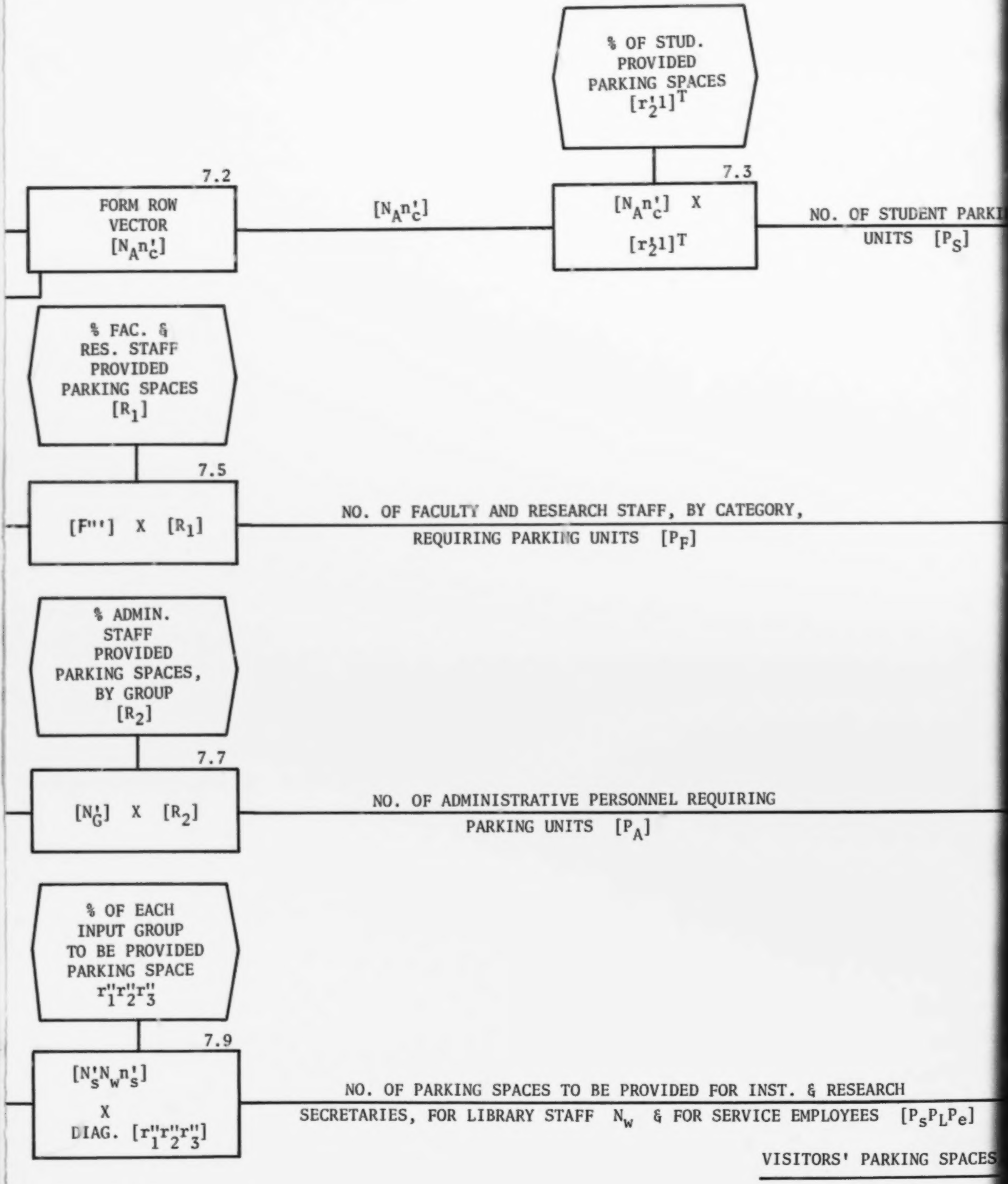

TOTAL STUDENT BODY N_T
6.1
NO. OF STUDENTS TO BE HOUSED, BY CATEGORY $[n'_q]$
$\sum_{q=1}^{5} n'_q$
TOTAL STUDENTS TO BE HOUSED N'''_q
N_T
TOTAL NO. OF PROFESSIONAL FACU
TOTAL NO. OF RESEARCH STAFF N
ADMINISTRATIVE PERSONNEL BY GROUP $[n_g]$
8
Σ
g=1
INSTRUCTIONAL & RESEARCH SECRETARIES, BY DEPT. $[n''_s]$
2d
Σ
s=
NO. OF LIBRARY STAFF REQUIRING WORK FAC
TOTAL NO. OF SERVICE EMPLOYEES n'_s

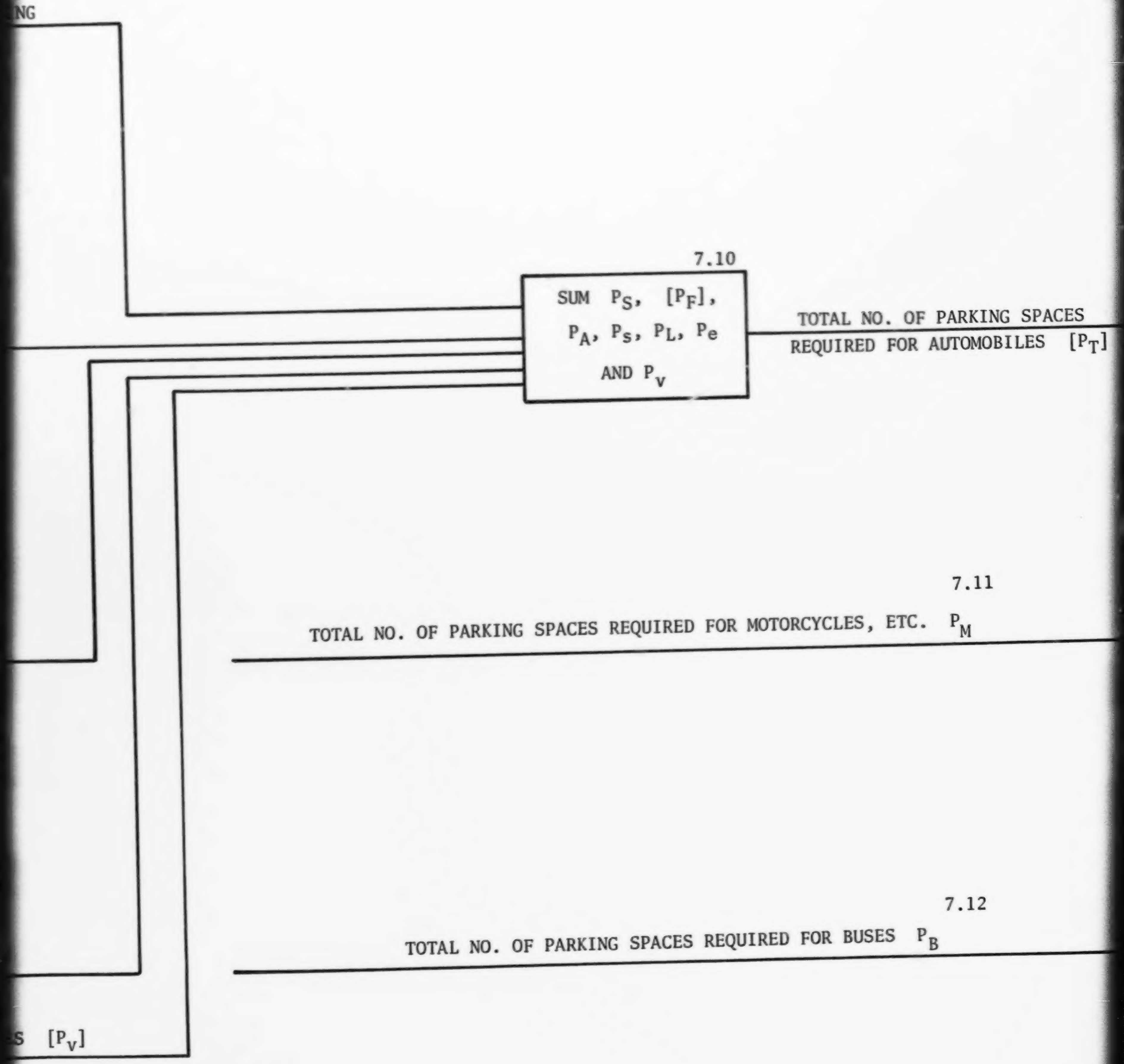

6.2
$- N'''_q$
NO. OF NON-RESIDENT STUDENTS $\overline{N}_T$
6.5
TY F_T
6.3
n_g
TOTAL NO. OF ADMIN. PERSONNEL N_G
6.4
n''_s
TOTAL NO. OF INSTRUCTIONAL & RESEARCH SECRETARIES N'_s
LITIES N_w
FORM ROW VECTOR
$[N'] =$
$[\overline{N}_T N'''_q F_T N_R N_G N'_s N_w n'_s]$
$[N']$


% OF EACH GROUP TO BE PROVIDED DINING FACILITIES
$p_1''', p_2''', \ldots p_8'''$
6.6
[N']
$[N'] \times [P_m''']$
MAXIMUM NO. OF DINING SPACES TO BE PROVIDED $[n_D]$

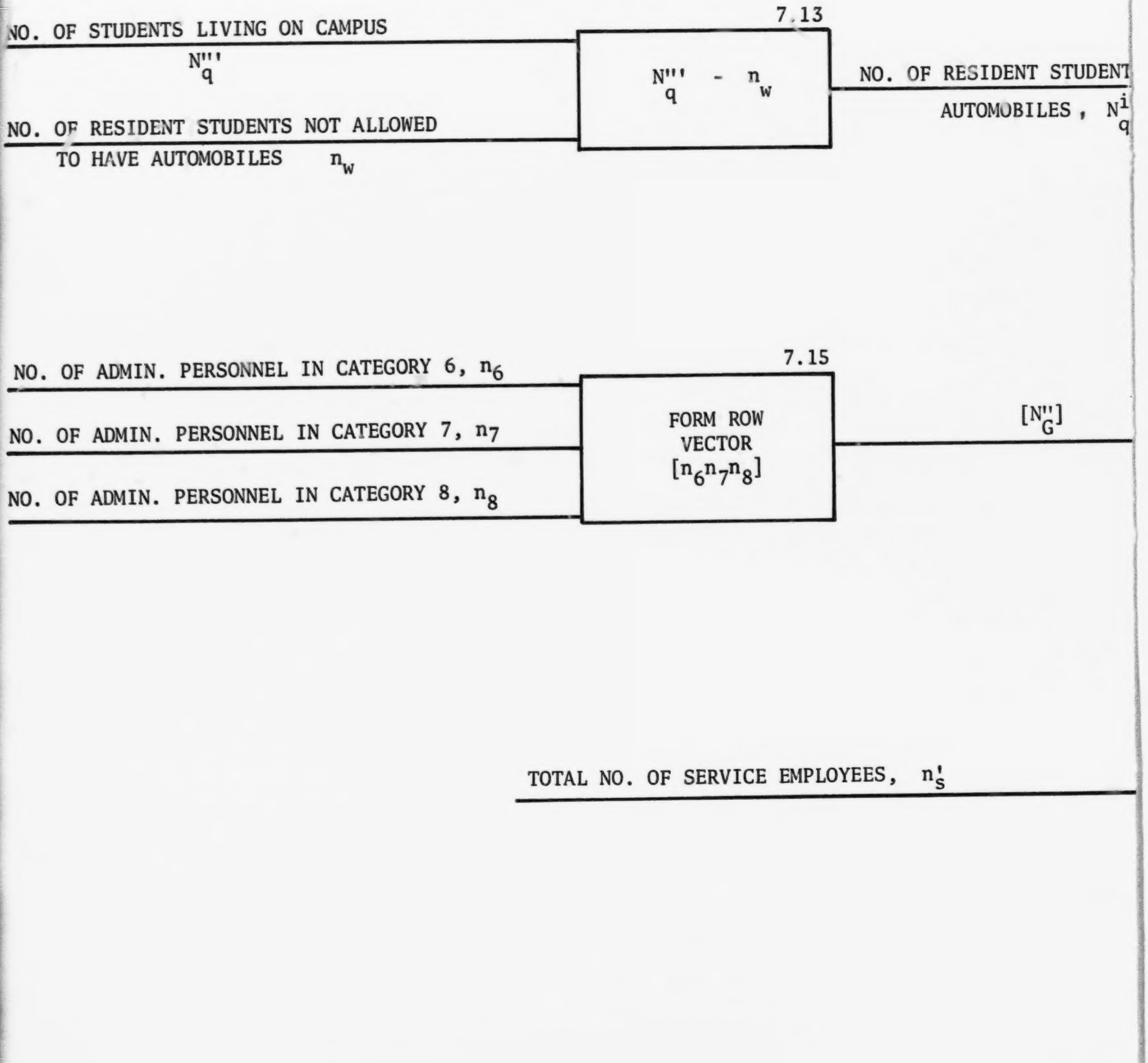
SUBMODEL NO. 7
PARKING FACILITIES (ON OR NEAR CAMPUS)

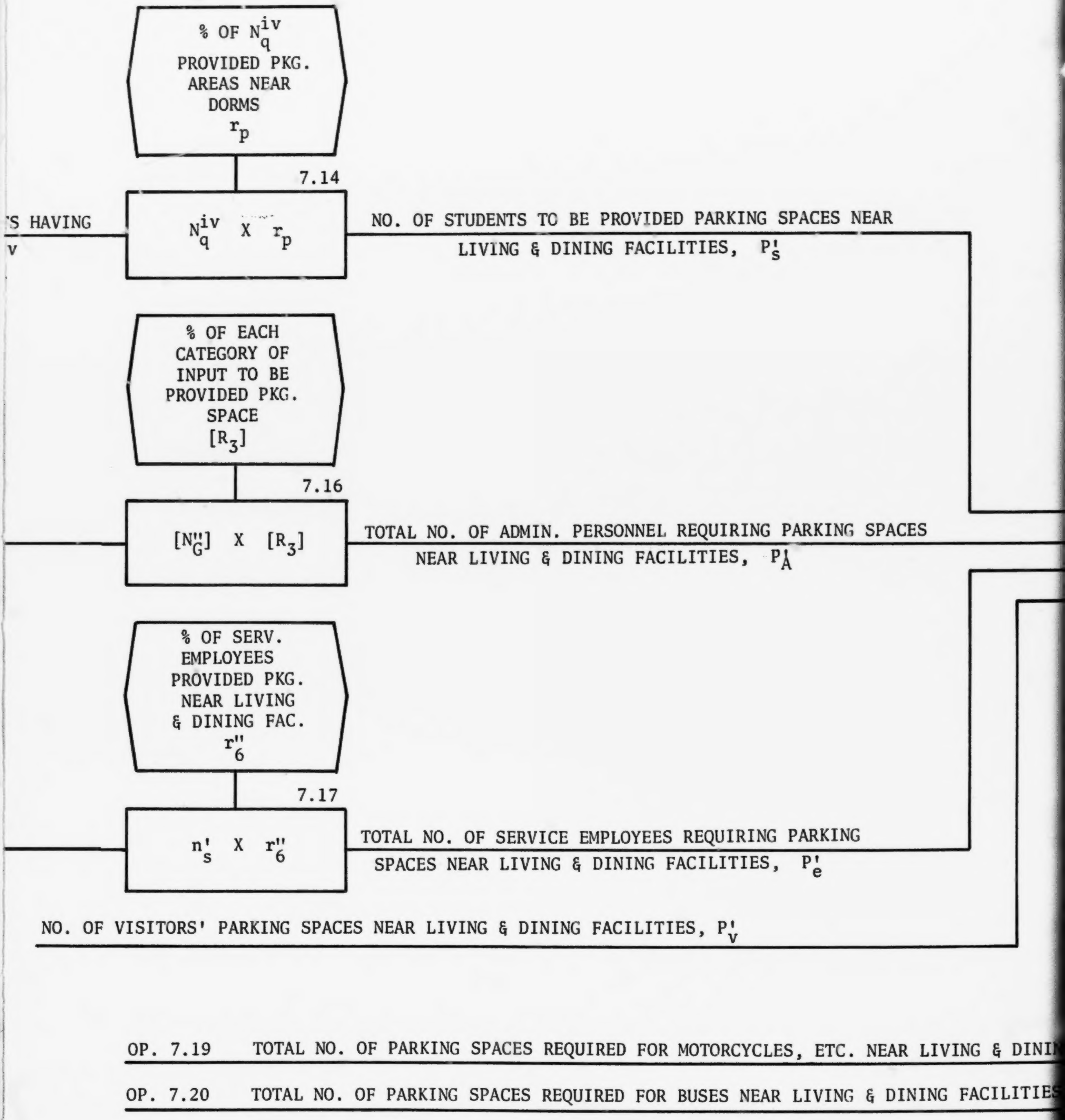

% OF NON-COMMUTING STUDENTS HAVING CARS r_1'
7.1
TOTAL NO. OF NON-COMMUTING STUDENTS N_T'
$N_T' \times r_1'$
NO. OF NON-COMMUTING STUDENTS HAVING CARS N_A
TOTAL NO. OF COMMUTING STUDENTS n_c'
NO. OF FACULTY, BY RANK [F]
PLUS PROJECT DIRECTORS, BY DEPT.
NO. OF RESEARCH STAFF EXCEPT PROJECT DIRECTORS BY DEPT. f_{i6}
7.4
FORM ROW VECTOR $[F''']$
TOTAL FACULTY & RESEARCH STAFF, BY CATEGORY $[F''']$
NO. OF ADMIN. STAFF, BY GROUP $[n_g]$
7.6
FORM ROW VECTOR $[n_1 n_2 \ldots n_5]$
$[N_G']$
NO. OF INST. AND RESEARCH SECRETARIES N_s'
NO. OF LIBRARY STAFF REQUIRING WORK FACILITIES N_w
NO. OF SERVICE EMPLOYEES n_s'
7.8
FORM ROW VECTOR $[N_s' N_w n_s']$
$[N_s' N_w n_s']$

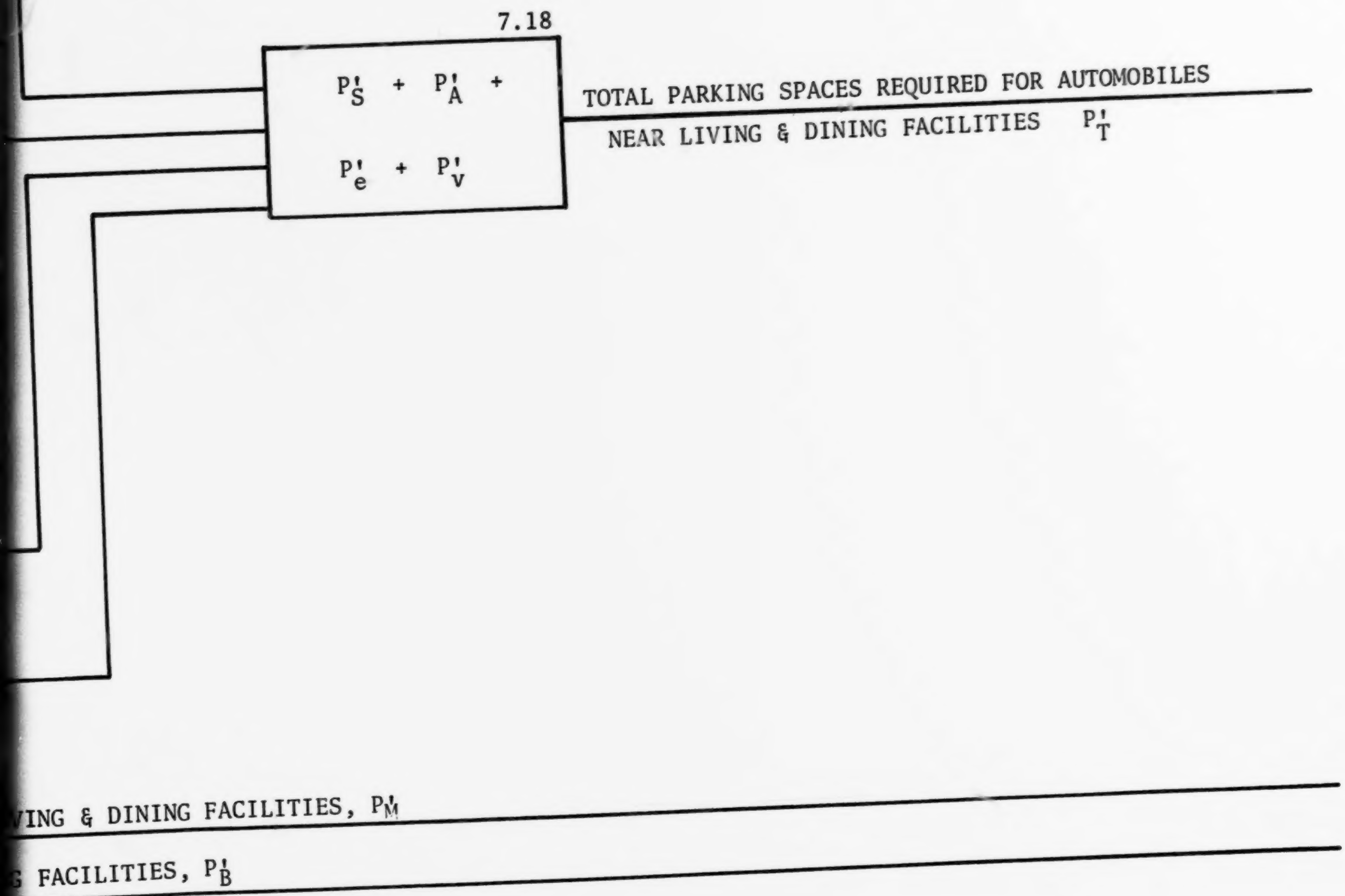

% OF STUD. PROVIDED PARKING SPACES $[r_2'1]^T$
7.2
FORM ROW VECTOR $[N_A n_c']$
$[N_A n_c']$
7.3
$[N_A n_c']$ X $[r_2'1]^T$
NO. OF STUDENT PARKI
UNITS $[P_S]$
% FAC. & RES. STAFF PROVIDED PARKING SPACES $[R_1]$
7.5
$[F''']$ X $[R_1]$
NO. OF FACULTY AND RESEARCH STAFF, BY CATEGORY, REQUIRING PARKING UNITS $[P_F]$
% ADMIN. STAFF PROVIDED PARKING SPACES, BY GROUP $[R_2]$
7.7
$[N_G']$ X $[R_2]$
NO. OF ADMINISTRATIVE PERSONNEL REQUIRING PARKING UNITS $[P_A]$
% OF EACH INPUT GROUP TO BE PROVIDED PARKING SPACE $r_1''r_2''r_3''$
7.9
$[N_s' N_w n_s']$ X DIAG. $[r_1''r_2''r_3'']$
NO. OF PARKING SPACES TO BE PROVIDED FOR INST. & RESEARCH SECRETARIES, FOR LIBRARY STAFF N_w & FOR SERVICE EMPLOYEES $[P_s P_L P_e]$
VISITORS' PARKING SPACES


ING
7.10
SUM P_S, [P_F], P_A, P_s, P_L, P_e AND P_v
TOTAL NO. OF PARKING SPACES REQUIRED FOR AUTOMOBILES [P_T]
7.11
TOTAL NO. OF PARKING SPACES REQUIRED FOR MOTORCYCLES, ETC. P_M
7.12
TOTAL NO. OF PARKING SPACES REQUIRED FOR BUSES P_B
S [P_V]

SUBMODEL NO. 7
PARKING - ASSOCIATED WITH LIVING AND DINING FACILITIES


7.13
NO. OF STUDENTS LIVING ON CAMPUS
N_q'''
NO. OF RESIDENT STUDENTS NOT ALLOWED TO HAVE AUTOMOBILES n_w
$N_q''' - n_w$
NO. OF RESIDENT STUDENT
AUTOMOBILES , N_q^i
7.15
NO. OF ADMIN. PERSONNEL IN CATEGORY 6, n_6
NO. OF ADMIN. PERSONNEL IN CATEGORY 7, n_7
NO. OF ADMIN. PERSONNEL IN CATEGORY 8, n_8
FORM ROW VECTOR $[n_6 n_7 n_8]$
$[N_G'']$
TOTAL NO. OF SERVICE EMPLOYEES, n_s'


% OF N_q^{iv} PROVIDED PKG. AREAS NEAR DORMS r_p
7.14
'S HAVING
v
N_q^{iv} X r_p
NO. OF STUDENTS TO BE PROVIDED PARKING SPACES NEAR LIVING & DINING FACILITIES, P'_s
% OF EACH CATEGORY OF INPUT TO BE PROVIDED PKG. SPACE $[R_3]$
7.16
$[N''_G]$ X $[R_3]$
TOTAL NO. OF ADMIN. PERSONNEL REQUIRING PARKING SPACES NEAR LIVING & DINING FACILITIES, P'_A
% OF SERV. EMPLOYEES PROVIDED PKG. NEAR LIVING & DINING FAC. r''_6
7.17
n'_s X r''_6
TOTAL NO. OF SERVICE EMPLOYEES REQUIRING PARKING SPACES NEAR LIVING & DINING FACILITIES, P'_e
NO. OF VISITORS' PARKING SPACES NEAR LIVING & DINING FACILITIES, P'_v
OP. 7.19 TOTAL NO. OF PARKING SPACES REQUIRED FOR MOTORCYCLES, ETC. NEAR LIVING & DINI
OP. 7.20 TOTAL NO. OF PARKING SPACES REQUIRED FOR BUSES NEAR LIVING & DINING FACILITIES


7.18
$P'_S + P'_A +$
$P'_e + P'_v$
TOTAL PARKING SPACES REQUIRED FOR AUTOMOBILES
NEAR LIVING & DINING FACILITIES P'_T
VING & DINING FACILITIES, P'_M
G FACILITIES, P'_B